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ГЕОФИЗИКА

НЕОТЕКТОНИКА И СЕЙСМИЧНОСТЬ БАССЕЙНА ПРИСДВИГОВОГО РАСТЯЖЕНИЯ ЭРЗУРУМ (*Восточная Турция*)

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Областью исследования является бассейн присдвигового растяжения Эрзурум, расположенный в Восточно-Анатолийском тектоническом блоке, контролируемом сдвиговыми неотектоническими процессами с начала четвертичного периода. Четвертичный бассейн Эрзурум составляет около 1–30 км в ширину, 90 км в длину и является активно развивающейся сдвиговой депрессией. На востоке-юго-востоке он ограничен зоной левостороннего сброса Эрзурум-Думлу, на севере–северо-западе — зоной левостороннего сброса Ашкале, а на западе — зоной взброса Башкой-Кандилли и субвертикальной зоной разлома с диагональным смещением Илика. Бассейн присдвигового растяжения Эрзурум развивался в результате деформации и разделения более древней субширотной межгорной впадины. Образовавшийся бассейн выполнен пологозалегающими (недеформированными) и неуплотнёнными осадками мощностью 0.5 км, перекрывающими с угловым несогласием деформированные (складчатые и разломные) породы фундамента дочетвертичного возраста. Осадки сложены крупнозернистыми породами краевой фации (приразломная терраса, конус выноса и наложенные отложения) и более мелкозернистыми породами депоцентральной фации (богатые органическим материалом пойменные и болотные осадки). Среди этих литофаций наблюдаются отложения всех градаций.

В бассейне сдвигового растяжения Эрзурум наблюдается достаточно высокая сейсмичность. Магнитуда сильных землетрясений в зоне активных разломов (например, разлома Эрзурум) достигает M_w = 7.0, что подтверждено примерами как древних, так и недавних землетрясений. Многочисленные населённые пункты — большие города (например, Эрзурум), округа, малые города и небольшие деревни с общим населением более 766 тыс. человек — расположены внутри бассейна сдвигового растяжения Эрзурум или на его окраинах, граничащих с активными разломами, несущими угрозу разрушительных землетрясений. В связи с этим необходимо построить крупномасштабную карту сейсмической опасности, используя как параметры активных разломов, так и данные о насыщенных водой отложениях бассейна. Эта карта должна использоваться для анализа опасности землетрясений и перепланировки всех видов сооружений в Эрзуруме и других населенных пунктах данного региона.

Эрзурум, бассейн присдвигового растяжения, сдвиговая неотектоника, активный разлом, Восточно-Анатолийский тектонический блок

NEOTECTONICS AND SEISMICITY OF ERZURUM PULL-APART BASIN, EAST TURKEY

A. Koçyiğit and M.C. Canoğlu

The study area is the Erzurum pull-apart basin located in the East Anatolian Tectonic Block (EATB), which is under the control of a strike-slip neotectonic regime since the beginning of the Quaternary. The Quaternary Erzurum pull-apart basin is an about 1–30 km wide, 90 km long and actively growing strike-slip depression. It is bounded by the Erzurum-Dumlu sinistral strike-slip fault zone to the east–southeast, by the Aşkale sinistral srike-slip fault zone to the north–northwest, and by the Başköy-Kandilli reverse fault zone and the N–S-trending Ilıca oblique-slip normal fault set to the west. The Erzurum pull-apart basin was evolved by the deformation and subdivision of an E–W-trending older intermontane basin. The new basin has a 0.5 km thick, flat-lying (undeformed) and unconsolidated fill, which overlies, with an angular unconformitry, the deformed (folded and faulted) basement rocks of pre-Quaternary age. Basin fill consists of coarser-grained marginal facies (fault terrace, fan, fan-apron, and superimposed fan deposits) and finer-grained depocentral facies represented by floodplain to organic material-rich marsh deposits. All gradations are seen among these lithofacies.

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The seismicity of the Erzurum pull-apart basin is quite high. The magnitude of the peak earthquake to be sourced from the active faults (e.g., the Erzurum fault) is about *Mw* = 7.0. This was proved by both the historical and recent earthquakes. Numerous settlements in the size of a large city (e.g., Erzurum), county, town, and small villages with a total population of over 766.000 are located in and along the active fault-bounded margins of the Erzurum pull-apart basin. They are under the threat of destructive earthquakes to be sourced from the margin–boundary faults. Therefore, based on both the active fault parameters and the water-saturated basin fill, a large-scale earthquake hazard map has to be prepared. This map has to be used in both the earthquake hazard to risk analyses and the redesign of city planning and all type of constructions in Erzurum and other settlements in this region.

Erzurum, pull-apart basin, strike-slip neotectonic regime, active fault, East Anatolian tectonic block

1. INTRODUCTION

The study area is the city of Erzurum and its near environ included in the East Anatolian tectonic block (EATB), which comprises the western section of the East Anatolian-Iranian plateau (Fig. 1). The study area is located outside and approximately 70 km away from the Karlıova junction, where the North Anatolian Fault System (NAFS) and the East Anatolian Fault System (EAFS) meet to each other.

Approximately 766,000 people are living in Erzurum region, where people are under the threat of earthquakes hazard. Although the seismicity of Erzurum and its near environ is very high, its source such as major strike-slip structures (e.g., dextral to sinistral strike-slip faults, oblique-slip normal and thrust to reverse faults) exposing in and adjacent to the study area have not been well-identified until the present study. A number of strike-slip basins are also exposed well in the EATB. However they have not been mapped at 1/25.000 scale and examined in detail. One of the well-developed strike-slip basins is the Erzurum pull-apart basin. Its evolutionary history and margin-boundary faults have not been defined well. Whereas actual sites of active faults and their various parameters (e.g., strike, dip amount to direction, length, type, slip rate, the return period and magnitude of peak earthquake to be sourced from the active faults) have a critical importance in the preparation of earthquake hazard map for the city of Erzurum and its near environ. In addition, the Erzurum pull-apart basin is also a geothermal field but this aspect of the basin has not been studied yet. A number of relatively local geological works were carried out for different purposes in the EATB (Aksoy and Tatar, 1990; Allen, 2004; Bozkuş, 1992, 1993, 1994; Bozkuş and Yılmaz, 1993; Ketin, 1950, 1977; Koçyiğit, 2013; Koçyiğit et al., 1985; Öztürk and Bayrak, 2005; Rathur, 1969; Temiz et al., 2002; Üner et al., 2010; Yarbaşı and Bayraktutan, 2003; Yılmaz et al., 1988) and regional (Dewey et al., 1986; Dhont and Chorowicz, 2006; Ercan et al., 1990; Göğüş and Pysklywec, 2008; Innocenti et al., 1982; Koçyiğit, 1983; Koçyiğit et al., 2001; McClusky et al., 2000; Notsu et al., 1995; Örgülü et al., 2003; Pearce et al., 1990; Reilinger et al., 1997, 2006; Şengör and Kidd, 1979; Şengör et al., 2008; Türkelli et al., 2003; Yılmaz et al., 1987, 1998). Except for the limited number of them, the most of local studies deal with general stratigraphy, petrography and deformation pattern of rocks. In contrast to the local works, the regional studies focus on genesis of collision volcanism of Neogene–Quaternary age, GPS measurements of present-day crustal movements, shortening of continental lithosphere, mantle lithosphere delamination to plateau uplift and general outline of neotectonics of the EATB.

In this frame, this paper aims to present the evolutionary history of the Erzurum pull-apart basin, newly detected margin-boundary faults, deformation pattern, some significant earthquakes and their sources under the light of new data obtained from field geological mapping, geological cross-section and observations carried out in the Erzurum pull-apart basin and its near environ. Thus it is thought that this study may make a contribution to the solution of seismic hazard problem and fill the gap in the neotectonic literature of the Erzurum region.

2. TECTONIC SETTING

The EATB is located to the east and outside the Karlıova junction between the North Anatolian and the East Anatolian Transform fault systems (NAFS and EAFS). It is bounded by both the Kelkit–Çoruh and the Borjomi–Kazbeg fault systems to the northwest, by the Lesser Caucasian suture to the north-northeast and by the Bitlis–Zagros suture zone to the south (Fig. 1*b*). The EATB is characterized by a strike-slip faulting-dominated neotectonic regime and related structures (Koçyiğit et al., 2001; Dhont and Chorowicz, 2006). Major neotectonic structures are the Aşkale, Başkale, Çobandede, Digor, Erzurum–Dumlu, Kağızman, Kura, and Narman sinistral strike-slip fault zones; the Aras, Balıkgölü, Iğdır, Karayazı-Erciş, Pambak-Sevan, Tutak-Çaldıran, and the Yüksekova dextral strike-slip fault zones; the Başköy, Everek, and Muş-Gevaş thrust to reverse fault zones (Fig. 1*b*) (Arpat et al., 1976; Cisternas et al., 1989; Dhont and Chorowicz, 2006; Horasan and Boztepe, 2006; Koçyiğit, 1985; Koçyiğit et al., 1985, 2001, 2013; Şaroğlu and Yılmaz, 1986; Şaroğlu et al., 1984, 1987; Rebai et al., 1993). These fault zones reactivated and led to the occurrence of a series of large and devastative

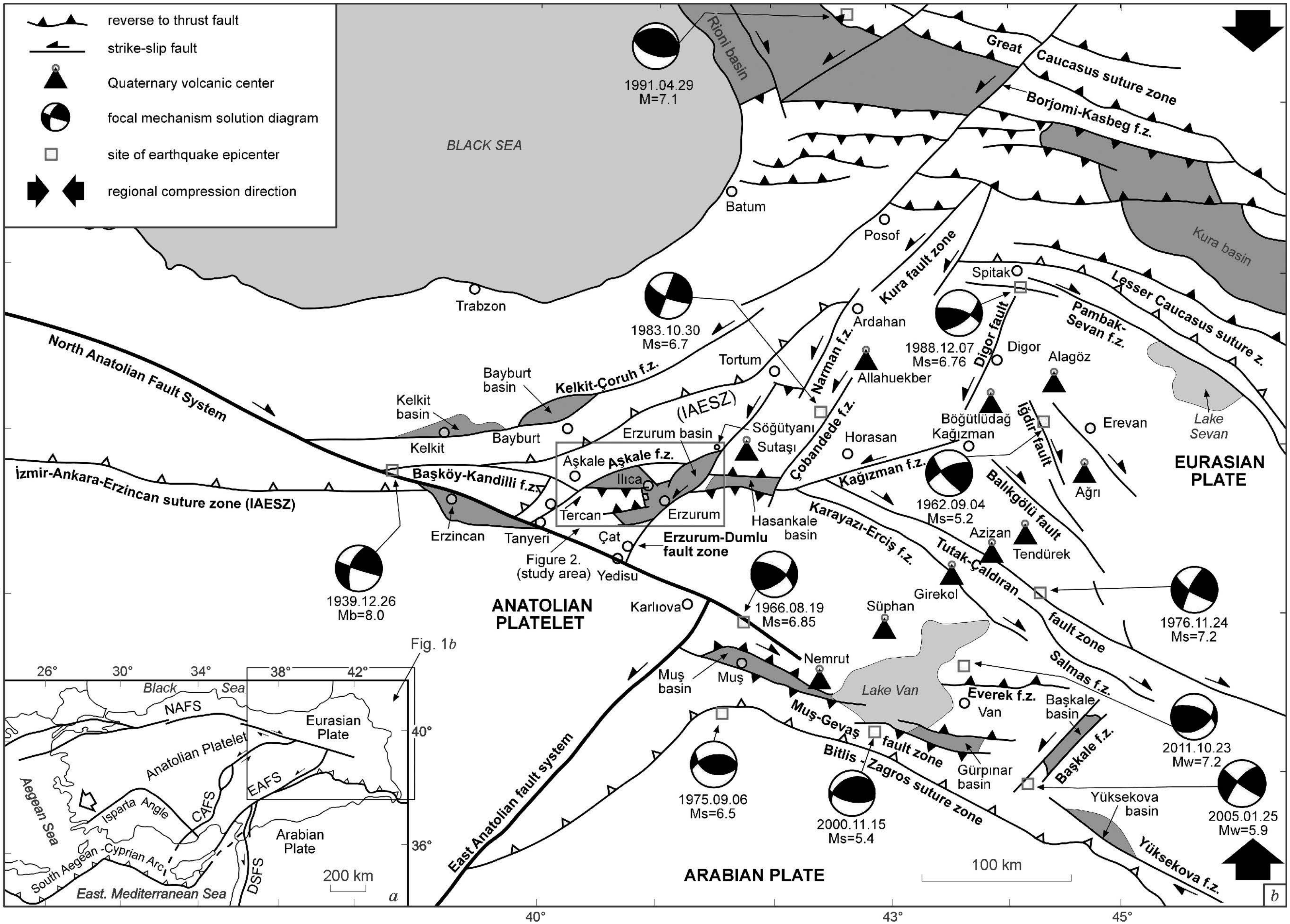


Fig. 1. ***a***, **Simplified map showing the plate tectonic configuration of Turkey and its near environ. CAFS, Central Anatolian Fault System; DSFS, Dead Sea Fault System; EAFS, East Anatolian Fault System.** ***b***, **Simplified seismotectonic map of the East Anatolian Tectonic Block (EATB) and adjacent area (numbers in circles correspond to the numbers of earthquakes listed on Table 2)**

earthquakes in last century. These seismic events and their focal mechanism solution diagrams (Fig. 1*b*) reveal that the strike-slip neotectonic regime and related structures in EATB are being governed by a stress system, in which the major principal stress axis (σ1) is operating in an approximately N-S (NNW-SSE) direction while the intermediate principal stress axis (σ2) is in a vertical position (Ambraseys, 1983, 2001; Ambraseys and Jackson, 1998; Eyidoğan et al., 1991; KOERI, 2011; Tan et al., 2008). However another tectonic regime for the EATB is suggested by Göğüş and Pysklywec (2008). According to these authors, the EATB is the site of lithospheric thinning, plateau uplift, heating and syn-convergent extension resulted from the delamination of the mantle lithosphere, i.e., western section of the EATB is the site of extension, while its only northern and southern tips are the sites of contraction. They have also reported that the Kağızman, Tuzluca, Hınıs, Karlıova, and Muş basins are the E–W trending and normal fault-controlled extensional basins developed as a natural response to the syn-convergent extension. In contrast to the idea of these authors, there is a big discrepancy between the site of extension they suggested and the nature of both structures and style of deformation patterns observed in the EATB (Dhont and Chorowicz, 2006; Koçyiğit et al., 2001, 2013; Özkaymak et al., 2011). Because, the local and shallow-seated extension in EATB is related to strike-slip tectonic regime and it is not consistent with the structures observed in this region. The western part of the EATB is shaped by a series of en echelon faults such as the E–W trending thrust to reverse faults, N–S-trending extensional features such as oblique-slip normal faults and fissures, NE- and NW-trending strike-slip faults and related pull-apart basins, i.e., the Kağızman, Tuzluca, Hınıs, Karlıova, and Muş basins are strike-slip fault-controlled pull-apart basins, not normal fault-controlled grabens (Fig. 1*b*). Consequently the new field and seismic data to be presented in this paper reveal strongly the predominancy of strike-slip neotectonic regime and related deformation pattern rather than tensional tectonic regime in the EATB (Fig. 1*b*).

3. STRATIGRAPHIC OUTLINE OF ERZURUM REGION

In general, the rocks exposing in the study area are divided into two categories based on the age and the tectonic period, during which they were formed. These are the paleotectonic units of pre-Quaternary age, and the neotectonic units of Quaternary age (Figs. 2, 3). Detailed stratigraphy of the paleotectonic units is outside the scope of the present paper. Therefore they have not been plotted separately on the map (Fig. 2*a*). However, paleotectonic units and their various characteristics (lithofacies, contact relationships, sedimentary features, etc.) were observed, examined and mapped at several type localities, where they are exposed well (rectangular inserts in Fig. 2*a*).

3.1 Paleotectonic units

Based on composition, degree of metamorphism and contact relationships, the paleotectonic rock units are also divided into two general categories: (a) basement rocks and (b) cover rocks. Basement rocks are represented by metamorphic rocks, coloured ophiolitic mélange (subduction complex) and a forearc sequence (the Anıkbaba Formation), while cover rocks consist of, from oldest to youngest, the Penek, Kemerkaya, and Gelinkaya Formations and the Erzurum Volcanics (Fig. 3). They are described briefly below.

3.1.1 Basement rocks

The metamorphic rocks are not exposed in the study area. They occur as blocks of dissimilar size in the coloured ophiolitic mélange. They are composed of low-grade metamorphic rocks such as marble, quartzite, calc-schist, amphibolite schist, quartz-sericite-chlorite schists, phyllite, metaconglomerate, metabasics, metatuff, metadacite and metagranite alternation with the tectonic intercalation of metaultramafics. The most widespread basement rock exposed in and adjacent to the study area is the coloured ophiolitic mélange. It is here termed as the Anatolian nappe. It occurs in all-sized and discontinues outcrops within the E–W-trending İzmir–Ankara–Erzincan suture zone running throughout northern Turkey (Fig. 1b). The Anatolian nappe is characterized by a subduction complex originated from the closure of northern Neo-Tethys. The subduction complex is a chaotic tectonosedimentary mixture of various blocks of dissimilar facies, age, origin and size set in an intensely sheared and ophiolitic clasts-rich scaly matrix. The highly silicified to calcified serpentinite, peridotite, gabbro, diabase, spilitic pillow lavas, tuff-tuffite, red to green radiolarian chert, red pelagic mudstone, massive to thick-bedded recristallized limestone, marble, various schists, deep marine pelagic cherty limestone, various volcanics of calk-alkaline character and ophiolitic olistostromes to breccias are most common blocks comprising the subduction complex. Its total thickness in and adjacent to the study area is over 1 km. The Anatolian nappe occurs as separate tectonic slices on both the Permo-Triassic metamorphic rocks (1 in Fig. 3) and the different stratigarphic horizons of cover rocks of dissimilar age and facies (2, 3 and 4 in Fig. 3). This type of occurrence reveals that the Anatolian nappe has been transported tectonically again and again after its growth and first emplacement up to early Quaternary time (Fig. 3). The Anıkbaba Formation, which is a forearc sequence in origin, starts with an unsorted basal conglomerate on the Anatolian nappe at the

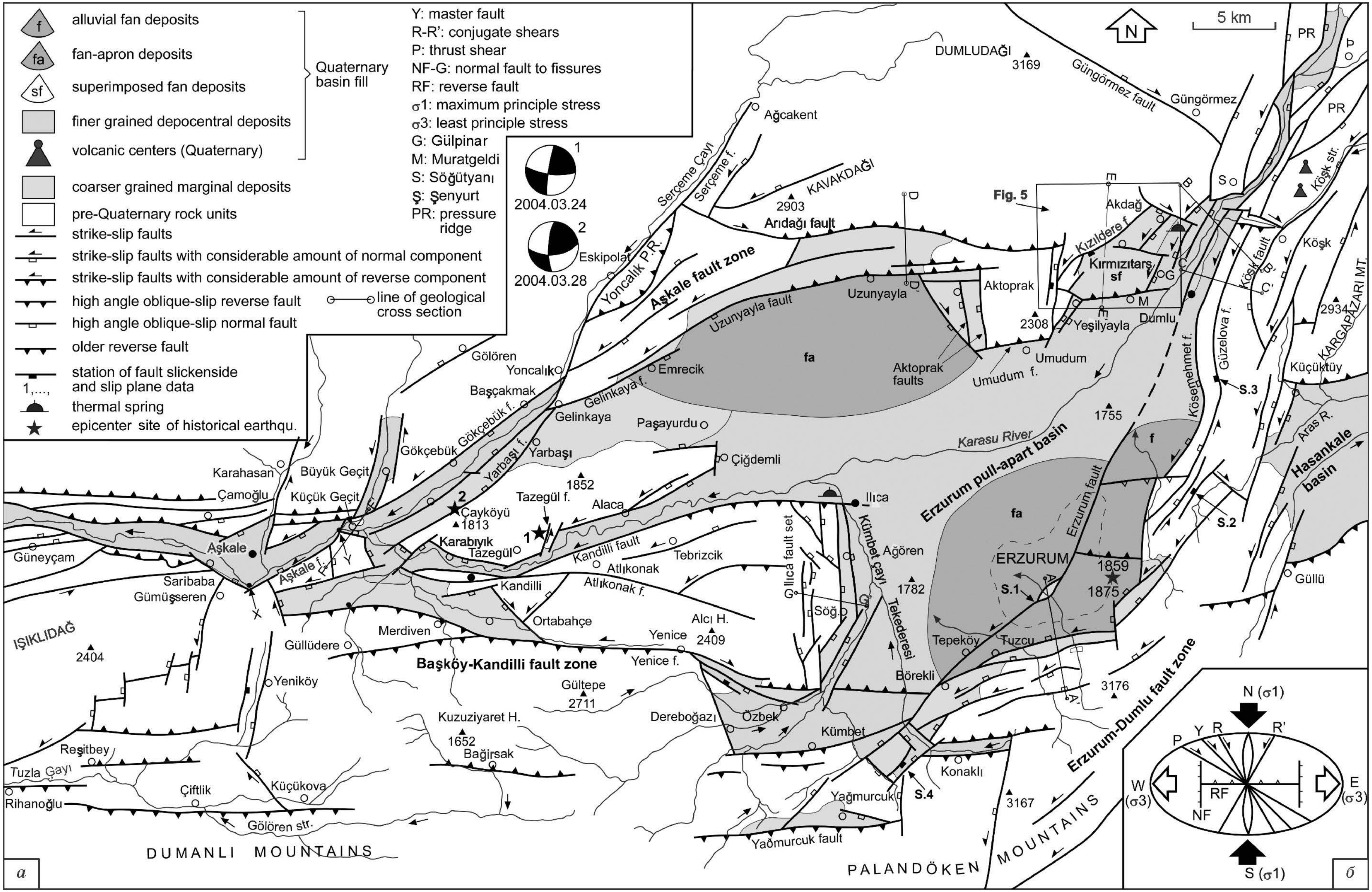


Fig. 2. *a*, Simplified neotectonic map of the Erzurum pull-apart basin and its near environ; *b*, strike-slip faulting pattern in the East Anatolian Tectonic block.

bottom and then continues upwards with a very regular sequence of thin-bedded to laminated sandstone-siltstone and pelagic limestone alternation. Basal conglomerate consists of angular to sub-rounded ophiolitic clasts derived directly from the underlying Anatolian nappe. Upper half of the Anıkbaba Formation is well-bedded and rich in foraminifers such as *Lepidorbitoides minor, Sirtina orbitoidiformis*, *Rugoglobigerina sp*. and *Globotruncana sp.* which imply to a late Maastrichtian age for the Anıkbaba Formation (Bozkuş, 1992).

3.1.2 Cover rocks

These are represented by four rock assemblages separated by the intervening erosional surfaces. These are, from oldest to youngest, the Penek, Kemerkaya, Gelinkaya Formations and the Erzurum Volcanics. They are underlain and overlain with angular unconformities by the pre-Tertiary basement rocks and the Quaternary neotectonic basin fills respectively (Fig. 3). Each of the cover sequences is described briefly below.

3.1.2.1 Penek Formation

This unit was first recognized, defined, mapped and reported as the Penek Formation by Bozkuş (1992). It is exposed to the west and outside the study area. The Penek Formation displays both the erosional (stratigarphical) and the tectonic contact relationships with the older Anatolian nappe (Fig. 3). At the bottom it starts with a basal conglomerate of fan origin on the erosional surface of the Anatolian nappe and then continues upwards with the fluvial sandstone, conglomerate and mudstone alternation. At the topmost, this fluvial sequence is succeeded by a coal seams-bearing lacustrine sequence of sandstone, siltstone, shale, marl and lacustrine limestone alternation overlain tectonically by the ophiolitic mélange of the Anatolian nappe (2 in Fig. 3) (Bozkuş, 1992). The ripple marks, load casts, slump folds and normal to reverse-type of growth faults are most common syn-sedimentary structures developed within the lacustrine sequence. The total thickness of the Penek Formation is 1.7 km. No fossil could be found in the Penek Formation. However it is overlain with an angular unconformity by the shallow-marine Kemerkaya Formation of early Miocene age. Based on its erosional top contact relationship with the Kemerkaya Formation (Fig. 3), an Oligocene age is assigned to the Penek Formation.

3.1.2.2 Kemerkaya Formation

The Kemerkaya Formation was first reported as the "Haneşdüzü Formation" by İlker, (1966) and Rathur (1969) in both the Hasankale and Tekman basins. However in the study area, this unit was first recognized, defined and reported as the Kemerkaya Formation by İnan, (1988). It is exposed well around Aşkale County to the west of the study area. Its type locality is the Kemerkaya Hill, where the Kemerkaya Formation is represented by two sub-sequences. These are the underlying transgressive marine sequence and the overlying regressive lagunar to fluvial sequence. In general, the upper sequence has been eroded partly and removed away leaving the underlying marine sequence behind in places owing to the long-term and rapid erosion as a natural response to the tectonic uplift caused by the Arabian-Eurasian post-collisional convergence after late Serravalian. At the bottom, lower transgressive sequence of the Kemerkaya Formation starts with a basal conglomerate on the erosional surfaces of both the ophiolitic mélange and the fluvio-lacustrine red clastics of the Penek Formation. Later on it continues upward with the sandstone, conglomerate, siltstone and sandy limestone alternation suceeded by a gray to yellow, thick-bedded (up to 4 m) to massif and nodular sandy reefal build-up. Basal conglomerates are variegated, unsorted and polygenetic in composition. Their thickness varies from 3 to 130 m. The lower marine sub-sequence grades upward into the lagunar to fluvial sequence composed of white to gray marl, plant debris-to coal seams-bearing shale, gypsum, claystone and limestone alternation. This lagunar sequence is suceeded again by yellow-red fluvial clastics. Total thickness of both sub-sequences is about 1.2 km. The package of the sandy reefal build-up is full of both macrofossils and foraminifers such as coral, spongea, algea, lamellibranchiata, gastropoda, clypeaster, Schizaster, Echinolampas, *Ostrea crassicostata, Miogypsina irregularis, Miogypsina mediterranea, Miolepidocyclina burdigaliensis, Amphistegina sp. and Lepidocyclina sp.* (Ketin, 1950; İlker, 1966; Rathur, 1969). These rich fossil assemblages of the Marine sequence of the Kemerkaya Formation indicate an early Miocene (Burdigalian) age for at least lower section of the formation. In addition upper section of the Kemerkaya Formation is overlain with an angular unconformity by both the Upper Miocene-Pliocene Erzurum Volcanics and a volcano-sedimentary sequence (the Gelinkaya Formation) (Rathur, 1969). Based on this erosional top contact relationship, the Kemerkaya Formation is older than Late Miocene. Consequently, the lower sub-sequence (the reefal build-up) of the Kemerkaya Formation is the last shallow-marine key unit exposed widely in the EATB. Its regional regression during Serravalian time implies to the emergence of a significant tectonic event, the continent-continent collision of the Arabian to Eurasian plates and uplift of the Anatolian-Iranian plateau.

3.1.2.3 Erzurum Volcanics

The Erzurum Volcanics are the most widespread rocks exposed in the EATB. Their distribution, composition, geochemical characteristics and age were previously studied and reported as the Erzurum-Çat Volcanics

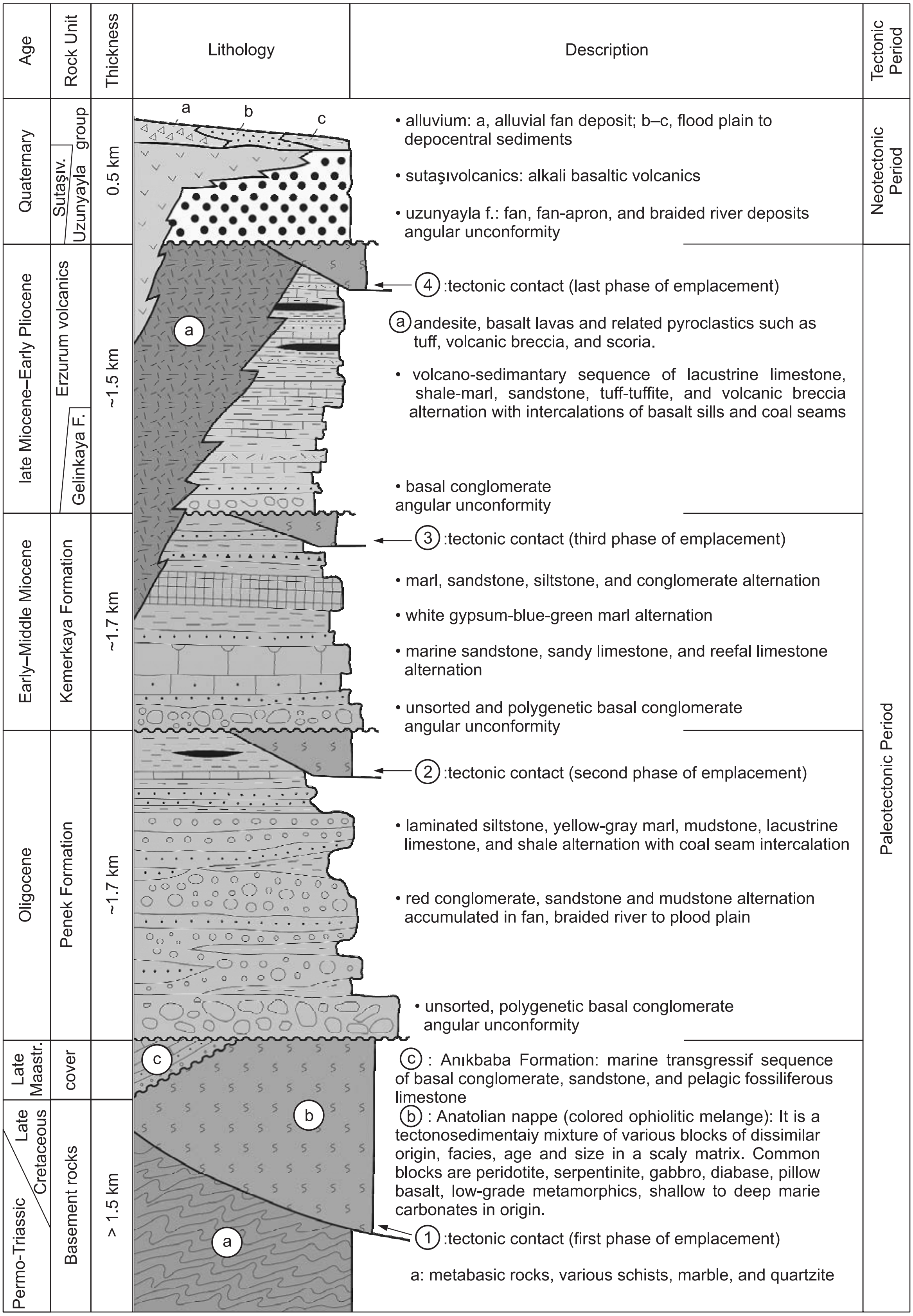


Fig. 3. Generalized to combined tectonostratigraphical columnar section of the Erzurum region.

by Innocenti et al. (1982), the Kargapazarı Volcanics by İnan (1988), the Erzurum Volcanics by Ercan et al. (1990), the Karakurt Volcanics by Bozkuş (1993) and the Palandöken Volcanics by Yarbaşı and Bayraktutan (2003), respectively. More general name (the Erzurum Volcanics) was preferred in the present study. The Erzurum Volcanics are also widely exposed throughout the faulted to uplifted whole margins of the Erzurum pull-apart basin. They have cross-cutting contact relationships with the pre-Upper Miocene rocks while they display both vertical to lateral gradations with the volcano-sedimentary sequence of the Gelinkaya Formation (Fig. 3). At the top, Erzurum Volcanics are overlain tectonically by a tectonic slice of the Anatolian nappe. However they are overlain with an angular unconformity by the Quaternary Uzunyayla formation (neotectonic basin fill) but crossed by the Sutaşı basalt of Quaternary age respectively (Fig. 3). In general, Erzurum Volcanics occur in strato- and single volcanic centers, fissure eruptions, domes, columns and thick covers of both lavas and pyroclastites. They are composed mostly of gray-pinkish andesite, rhyolite, rhyodacite, dacite, trachyte and black basalt. Their total thickness is about 1.5 km. Based on the geochemical analyses carried out by Bilgin (1987), Innocenti et al. (1982) and Ercan et al. (1990), the Erzurum Volcanics are mostly calc-alkaline and rarely tholeiitic to alkaline in nature. In the same way the isotopic age determinations carried out on samples indicate an age range between 8 Ma and 4.61 Ma (late Miocene-early Pliocene) for the Erzurum Volcanics (Innocenti et al., 1982; Ercan et al., 1990).

3.1.2.4 Gelinkaya Formation

This unit was first recognized, mapped, defined and reported as the Gelinkaya Formation by Arpat (1965). It is exposed at the mappable scale of 1/25,000 around Tazegül, Alaca, Gelinkaya, Çiğdemli, and Ilıca settlements to the west of the study area (Fig. 2a). However it also occurs rarely as small-scaled outcrops in and adjacent to the other margins of basin due to the thick and widespread cover of the Quaternary basin fill. At the bottom, the Gelinkaya Formation starts with a basal conglomerate on the erosional surface of various rocks of dissimilar age and facies such as the ophiolitic mélange and the Kemerkaya Formation, and then continues upward with the alternation of sandstone, siltstone, mudstone, gray-green marl, claystone, clayey limestone, tuff, tuffite, and basalt sills. Sequence also contains intercalations of 1 to 4 m thick and lens-shaped fluvial conglomerate and very hard basaltic breccia horizons in places. Upper half of the sequence is characterized by the coal seams-bearing green-brown shale, laminated siltstone and mudstone alternation deposited in a lacustrine setting. Basal conglomerate is gray-yellow-red, unsorted and polygenetic in composition. At the topmost the Gelinkaya Formation is tectonically overlain by a slice of ophiolitic mélange (4 in Fig. 3). Both the Gelinkaya Formation and its tectonic cover altogether are overlain with an angular unconformity by the Quaternary basin fill (Uzunyayla Formation). Common synsedimentary structures developed and preserved in the Gelinkaya Formation are ripple marks, trough to planar cross-bedding, delta structure characterized by nearly horizontal top beds and dipping fore-set beds, slump folds, load casts and flame structure. Particularly the delta structures, current ripples and cross-bedded structures altogether indicate that sediments have been transported from west to east during the deposition of the Gelinkaya Formation (Fig.4). Marls and claystone horizons of the Gelinkaya Formation are rich in *Ilyocypris gibba, Cyprinotus salmus, Dreissensia cf. Polymorpha, Candona cf. Compressa and Dreissensia aff. Rostriformis* (Bozkuş, 1993; Rathur,1969). The lithofacies, fossil to coal content and sedimentary structures altogether indicate that the Gelinkaya Formation was deposited in a lake and coastal plain accompanied by a volcanic activity during late Miocene–Pliocene. In addition, Based on the some Physical characteristics, the Gelinkaya Formation can be correlated with the Horasan Formation exposed well in the Hasankale basin located to the near east and outside of the Erzurum pull-apart basin (Fig. 2*a*). As a matter of fact, it was previously reported that these two basins have been interconnected as an approximately E–W-trending unique intermontane basin during the pre-Quaternary paleotectonic period (Bozkuş, 1993; Rathur, 1969; Şaroğlu and Yılmaz, 1986). But now, they are two separate strike-slip basins extending in different trends.

3.2 Neotectonic units

These are the units formed under the control of a strike-slip neotectonic regime prevailing since early Quaternary, i.e., they are the fill of strike-slip basin. The neotectonic units are represented by two rock assemblages in the Erzurum pull-apart basin. These are

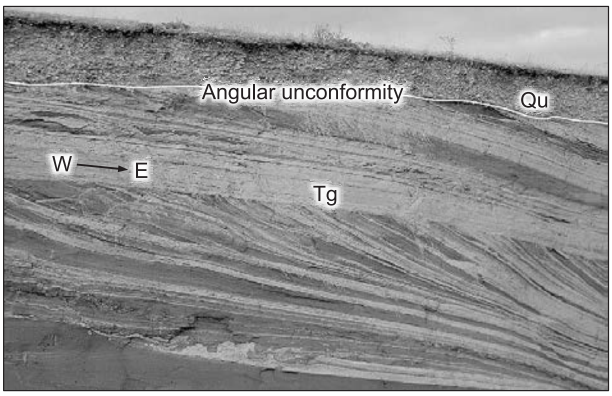


Fig. 4. Close-up view of the delta structure which indicates the paleocurrent flowed from west to east in the Upper Miocene–Lower Pliocene Gelinkaya Formation (view to N).

the basaltic lavas of fissure eruption in origin and the fan to fluvial sedimentary assemblage. They are here informally named as the Sutaşı basalt and the Uzunyayla group, respectively (Fig. 3). Various members of the neotectonic units were observed and examined at type localities along the whole margins and inside the Erzurum pull-apart basin (rectangular inserts in Fig. 2*a*). They are described below.

3.2.1 Uzunyayla group

This unit is nearly flatlying (undeformed) except for the faulted contacts, where it is either squeezed up as pressure ridges or juxtaposed tectonically with the older paleotectonic units. The Uzunyayla group overlies originally with an angular unconformity the whole of paleotectonic units of pre-Quaternary age. It consists of several sedimentary packages. They can be subdivided into two categories based on the grain size and sites of their depositional settings. These are the coarser-grained marginal facies and the finer-grained depocentral facies. Marginal facies are, from bottom to top, the basal conglomerates, older fan-apron deposits and recent fan to fan-apron deposits. Depocentral deposits are the fluvial and flood plain to marsh deposits. The neotectonic units are plotted altogether in the same symbol on the simplified neotectonic map (Fig. 2*a*) due to its small scale, however they are illustrated separately on the larger-scaled maps carried out at their type localities (Rectangular inserts in Fig. 2*a*).

3.2.1.1 Basal conglomerates and older fan-apron deposits

These are the most widespread members of the Uzunyayla group. They are exposed well at the whole faulted-margins of the Erzurum pull-apart basin. They occur either as the pressure ridges and/or faulted, uplifted, dissected and fault-suspended terrace conglomerates (Fig. 5). As a natural response to the movement along the active faults, coarser-grained deposits are steeply-tilted, sub-vertical and overturned in position within the fault-bounded pressure ridges and along the separate faulted contacts. However they are nearly flat-lying away from these structures. One of the type localities of the older fan-apron deposits is the Uzunyayla–Arıbahçe area located at the northern margin of the Erzurum pull-apart basin. In this area older fan-apron deposits display faulted contact relationships with the older Erzurum volcanics and recent fan-apron deposits along the Banasordere and Uzunyayla faults respectively, i.e., they are exposed as the fault-suspended terrace deposits. At the first type locality, older fan-apron deposits consist of gray, unsorted, weakly lithified to loose, massive and polygenetic boulder-block conglomerate with the intercalations of coarser-grained sandstone lenses. Components of conglomerates are semi-rounded and rounded in shape and range from a few cm to 1.5 m in size. They are mostly andesite, basalt, dasite, trachyte, recristallized limestone, reefal limestone, sandstone, serpentinite, spilite, radiolarite and chert in composition. They are set in a volcanic material-rich sandy matrix bounded weakly by calcite cement. Total thickness of the fault terrace deposits in this area is over 0.4 km.

The second type locality of both older and younger fan-apron deposits is the Yeşilyayla–Kırmızıtaş areas located at the northeast margin of the Erzurum pull-apart basin (Fig. 5). In this area, older fan apron deposits are confined among the NE-trending Kızıldere and Gülpınar sinistral strike-slip faults, the NW-trending İkiztepeler dextral strike-slip fault and approximately E–W-trending Muratgeldi reverse fault (Fig. 5). Older fan-apron deposit is in the faulted contact with both the older Erzurum volcanics and the recent depocentral sediments while it is superimposed by a newly developing alluvial fan deposits. This relationship implies to the activeness of the margin-boundary faults. This is also evidenced by a series of young transverse streams, along which older fan-apron deposits have been crossed and incised deeply. These deep and narrow beds of drainage system have formed as a natural response to the movement along the margin-boundary faults. Conglomerates are unsorted, polygenetic, well-lithified and structureless. They are composed mostly of sub-rounded to rounded andesite and basalt but rarely lacustrine limestone and sandstone pebbles, boulders and blocks (up to 2 m in diameter) set in a volcanic material-rich sandy matrix as in the case of the Uzunyayla–Arıbahçe area. All-sized clasts of the Erzurum Volcanics have been transported and accumulated in alluvial fans by the high energy debris flows and drainage system. Later on they have been faulted, uplifted, dissected and exposed as the fault-suspended terrace conglomerate. Total thickness of older fan-apron deposits is about 0.3 km.

3.2.1.2 Younger fan-apron deposits and recent alluvial fans

They are more widespread along both the northern and southern fault-bounded margins of the Erzurum pull-apart basins (Fig. 2*a*). They form approximately 1–8 km wide, 7–20 km long and lens-shaped blanket of unconsolidated sediments. They have been formed by the coalescence of two packages of sediments. These are the alluvial fan deposits and the slope screes or talus. Fans have been formed at the mouths of transverse streams, which emanate from the highest peaks of the margin-bounding faulted highlands and then flow towards the basin in down-slope direction. All-sized sediments of dissimilar facies have been eroded, transported and deposited in alluvial fans at the foot of steeply sloping fault-controlled basin margin. Therefore they display a gradation from the coarsest in the apex to the finest in the distal section of fan. In addition sediments comprising the fans are sub-rounded and rounded in shape. In contrast, talus deposits are composed of unsorted and angular sediments transported and accumulated by gravity on both at the foot and slope of fault scarps. In time, these two packages of sediments have coalesced and resulted in a long and thick (up to 250 m) blanket, which covers particularly the northern and southern margins of the Erzurum pull-apart basin. One side of the blanket of fan-apron deposit is fault-bounded, while other side displays vertical and lateral gradation with the finer-grained depocentral deposits. Each fan included in the blanket of fan-apron deposits are flattened with a long axis running parallel to the general trend of the margin-bounding faults owing to the movement along the margin-boundary faults. However very recent fans, which are separated by an intervening short-term episode from the underlying fan-apron deposits, have not been deformed yet, i.e., they still retain their original shape. Consequently, the short-term erosional episode between the deformed blanket of fan-apron deposits and the non-deformed recent fans superimposed on it implies to the activeness of the faults, which controlled their deposition.

3.2.1.3 Depocentral deposits

These are weakly lithified to loose finer-grained sediments exposed along the axial plain of the Erzurum pull-apart basin. They consist of finer-grained sandstone, laminated siltstone, mudstone and organic material-rich claystone alternation. They also contain intercalations of 3–100 m long cross-bedded sandstone to conglomerate lenses and peat occurrences in places. All vertical and lateral gradations are seen between the coarser-grained fan-apron and finer-grained depocentral deposits. These sediments have been transported and deposited by an antecedent drainage system (Karasu River and its major tributaries), which drain the Erzurum pull-apart basin, inside their beds and adjacent flood plains. Based on borehole data, total thickness of the finer-grained sediments is over 0.4 km.

3.2.2 Sutaşı volcanics

In the EATB, the largest single to composite strato-volcanic centres, such as the Nemrut, Süphan, Grekol, Tendürek, Ağrı, Böğütlüdağ, Alagöz, and Allahuekber volcanoes, have been developed during the Quaternary neotectonic period (Fig. 1*b*). Two of these volcanic centres occur around Sutaşı Hill (near east of Köşk Town)

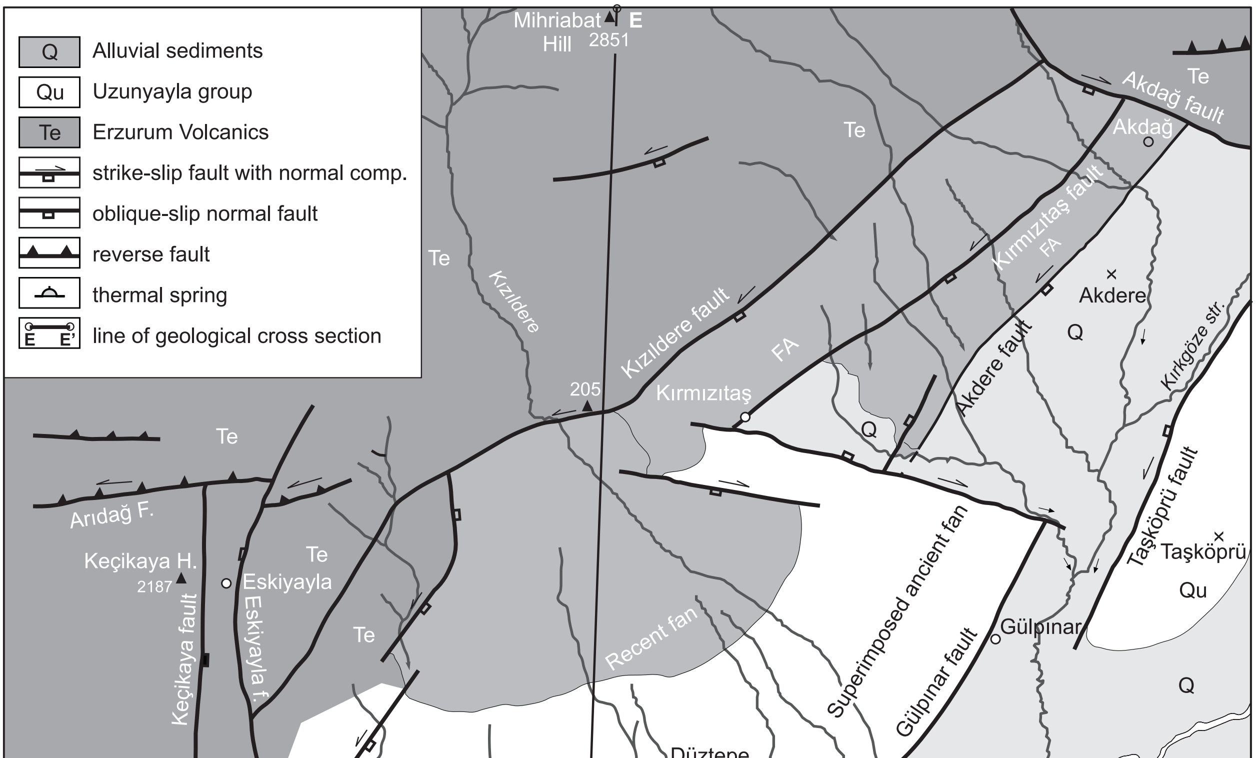


Fig. 5. Geological map of the northeastern section (Yeşilyayla–Kırmızıtaş area) of the Erzurum pull-apart basin.

along the shoulder of southeastern fault-bounded margin of the Erzurum pull-apart basin. The less-viscous basaltic magma has poured out of the N–S-trending fissures and then spread over an area of approximately 3 km^2. These black, highly vesicular basaltic lavas here are named as the Sutaşı volcanics. They also occur as a few meters to 5 m thick and long intercalations in the older fan-apron deposits of the Quaternary Uzunyayla group. In general, magmas of the fissure eruptions were generated from a heterogeneous mantle source based on both the major to trace element compositions and the isotope ratios (Yılmaz et al., 1998).

4. ACTIVE TECTONICS AND RELATED STRUCTURES IN ERZURUM REGION

4.1 Seismicity of East Anatolian Tectonic Block

4.1.1 Historical earthquakes

Seismicity of EATB is very high. This was proved once more by the occurrence of very recent devastative earthquakes, such as the 25 march 2004 Tazegül (Aşkale–Erzurum), the 28 March 2004 Alaca (Aşkale–Erzurum) and the 23 October 2011 Tabanlı (Van) earthquakes of Ms = 5.1, 5.3 and Mw = 7.2 respectively (KOERI, 2011; Bozkuş, 1993). Indeed, the earthquake hazard of settlements included in the EATB is very high. This is indicated by not only the recent seismic activity, but also by the historical earthquakes. It has been reported that twenty destructive seismic events of intensities (Io) between IX and X occurred in the EATB in the period between 869 A.D. and 1890 A.D. (Table 1). A number of people lost their lives, thousands of structures were ruined and the Nemrut volcano reactivated and led to the basaltic lavas pouring out of it during the 1441

Table 1. **Some significant destructive historical earthquakes took place in an near environ of the East Anatolian tectonic block**

No	Date	Coordinates	İntensity/ Magnitude	Geographic location	Risks	References
20	1890.05.20	39.90N - 38.80E	IX	Erzincan-Refahiye	?	Soysal et al. (1981)
19	1881.05.30	38.50N - 43.30E	IX, Ms=7.3	Van-Bitlis-Muş	Structure over 400 were ruined	Soysal et al. (1981) Irmak et al. (2012)
18	1875.11.01	39.90N - 41.30E	IX	Erzurum	?	Soysal et al. (1981)
17	1868.04.23	40.00N - 41.70E	IX	Erzurum-Kars(Hasankale)	?	Soysal et al. (1981)
16	1859.06.02	39.90N - 41.30E	IX	Erzurum	15 000 deaths, houses over 4000 were ruined	Soysal et al. (1981)
15	1784.06.18	39.50N - 40.20E	IX, Ms=7.6	Elmalı-Yedisu (Erzurum)	?	Ambraseys and Jackson (1998)
14	1766.10.09	?	IX	İspir	?	Ambraseys and Finkel (1995)
13	1715.03.08	?	IX	Van	?	Ambraseys and Finkel (1995)
12	1696.04.14	?	IX	Çaldıran (Van)	Most of structures were ruined, numerous deaths	Ambraseys and Finkel (1995)
11	1679.06.14	?	IX	Erevan (Armenia)	Over 8000 deaths, %70 of structures were ruined	Ambraseys and Finkel (1995)
10	1646.04.02	39.15N - 44.00E	IX	Van-Bitlis-Muş	Over 2000 deaths, % 80 of structures were ruined	Soysal et al. (1981) Ambraseys and Finkel (1995)
9	1584.06.17	39.75N - 39.50E	IX	Erzincan-Erzurum (Tercan-Çayırlı)	15 000 deaths	Soysal et al. (1981)
8	1575.11.05	?	IX	Erzincan	?	Ambraseys and Finkel (1995)
7	1482.12.21	39.75N - 39.50E	IX	Erzincan-Erzurum (Tercan-Çayırlı)	?	Soysal et al. (1981) Ergin et al . (1967)
6	1458.?.?	39.75N - 40.40E	IX	Erzincan-Erzurum (Tercan-Çayırlı)	32 000 deaths	Soysal et al. (1981)
5	1275.?.?	42.00N - 44.00E	IX	West of Tiflis	?	Soysal et al. (1981)
4	1268.?.?	39.79N - 40.40E	IX	Erzincan-Erzurum (Tercan-Çayırlı)	15 000 deaths	Soysal et al. (1981) Ergin et al . (1967)
3	1111.?.?	38.47N - 43.35E	IX	Van	?	Ergin et al . (1967)
2	1045.04.05	39.75N - 39.50E	IX	Erzincan (Tercan-Çayırlı)	?	Soysal et al. (1981)
1	869.?.?	40.00N - 44.00E	IX	Erevan (Armenia)	12 000 deaths	Soysal et al. (1981)

Bitlis-Muş-Van historical earthquake (Ambraseys and Finkel, 1995; Ambraseys and Jackson, 1998; Soysal et al., 1981; Ergin et al., 1967). In fact, there are no reliable data about the various historical earthquakes parameters such as occurrence time, site of epicenters, depth, magnitude and origin. Even though the ill-defined information about historical earthquakes, the 7 April 1646 and the 18 June 1784 seismic events seem to be very significant with respect to others. Based on the reassessment of historical earthquakes, the first event was a large devastative earthquake of Ms = 7.0 sourced from an approximately E–W trending active fault (the Gürpınar thrust fault) exposing along the northern margin of the Engil River valley (Ambraseys and Jackson, 1998). In the same way, the second event (18 June 1784 event) was also a large earthquake of magnitude Ms = 7.6 sourced from the WNW-trending Yedisu dextral-strike-slip fault, which is the master fault of the Erzincan–Karlıova section of the North Anatolian Fault System. Consequently, sources of these two large seismic events are in the nature of seismic gaps for the time slices of 368 yrs and 230 yrs respectively, i.e., these two active faults may move again and lead to the occurrence of large devastative earthquakes in the near future. In addition, 2 June 1859 and the 1 November 1875 historical seismic events have been sourced from the margin-boundary faults of the Erzurum pull-apart basin. They reveal that the seismicity in the Erzurum region is high as much as in the Van region (Koçyiğit, 2013).

4.1.2 Earthquakes in the period 1939–2011

Thirteen seismic events of magnitudes ranging from Ms = 5.3 to Ms = 8.0 were reported from the EATB and its near environ in the instrumental period (Table 2). Their epicenter locations (coordinates) imply to the

Table 2. **Significant destructive instrumental historical earthquakes took place in eastern Anatolia and near environ in the period of 1939–2011**

No	Date	Time	Coordinates	Focal Depth	Magnitude	Geographic location	Risks	Source of earthquakes	References
13	2011.10.23	13:41	38.90N - 43.60E	16	Mw = 7.2	Tabanlı (Van)	28 532 structures were damaged 644 deaths 200 000 people were migrated	reverse fault	Irmak et al. (2012) KOERI (2011)
12	2005.01.25	18:44	37.71N - 43.77E	13,7	Mw = 5.9	Sütlüce (Hakkari)	Two deaths, structure over 200 were collapsed	sinistral strike slip fault	HARVARD (2005)
11	2004.03.28	06:51	39.95N - 40.83E	5	Mw = 5.5	Aşkale (Erzurum)	Over 150 structures were ruined	sinistral strike slip fault	Tan et al. (2008) KOERI (2011)
10	2004.03.25	21:30	39.93N - 40.89E	10	Mw = 5.6	Aşkale (Erzurum)	9 deaths, over 300 structures were ruined	sinistral strike slip fault	Tan et al. (2008) KOERI (2011)
9	2000.11.15	15:05	38.41N - 42.95E	48	Mw = 5.7	Altınsaç (Gevaş)	?	reverse fault	ERD (2000)
8	1991.04.29	09:12	42.41N - 43.67E	5	Mw = 6.97	Racha (Georgia)	200 deaths, 60 000 Homeless	thrust fault	Ambraseys (2001)
7	1988.12.07	07:41	40.94N - 44.29E	10	Mw = 6.76	Spitak (Armenia)	25 000 deaths, %90 of Spitak was destroyed	reverse fault with strike slip comp.	Ambraseys (2001) Cisternas et al. (1989)
6	1983.10.30	04:12	40.28N - 42.18E	15	Mw = 6.74	Horasan	1330 deaths, 2341 structure were ruined	sinistral strike slip fault with reverse comp.	Ambraseys (2001) Toksöz et al. (1983)
5	1976.11.24	12:22	39.10N - 44.00E	10	Mw = 7.2	Çaldıran (Van)	3840 deaths, 9232 structures were collapsed	dextral strike slip fault	Ambraseys (2001) Toksöz et al. (1977)
4	1975.09.06	09:20	38.55N - 40.75E	5	Mw = 6.5	Lice (Diyarbakır)	2384 deaths, 8149 structures were ruined	reverse fault with strike slip comp.	Ambraseys (2001)
3	1966.08.19	12:22	39.20N - 41.40E	16	Mw = 6.85	Varto	2529 deaths, 34 000 structures were ruined	reverse fault with strike slip comp.	Ambraseys (2001) Eyidoğan et al. (1991)
2	1962.09.04	22:59	40.00N - 44.00E	33	Mw = 5.8	Iğdır	One death, structures over 100 were collapsed	dextral strike slip fault	Eyidoğan et al. (1991)
1	1939.12.26	23:57	39.70N - 39.70E	35	Mw = 8.0	Koçyatağı (Erzincan)	40 000 deaths, 360 km long surface fractures formed	dextral strike slip fault	Tan et al. (2008) Eyidoğan et al. (1991)

existence of a number of active fault zones of dissimilar nature in this region, even though they have been previously ill-defined (Fig. 2*b*). Five of these seismic events are the largest and destructive earthquakes caused to heavy damage and much loss of life in the EATB. These are the 26 December 1939 Erzincan, 24 November 1976 Çaldıran, 30 October 1983 Horasan-Narman, 7 December 1988 Spitak and the 23 October 2011 Tabanlı (Van) earthquakes of magnitudes Ms = 8.0, 7.2, 6.74, 6.76 and 7.2, respectively (Table 2) (Ambraseys, 2001; Cisternas et al., 1989; Eyidoğan et al., 1991; Irmak et al., 2012; KOERİ, 2011; Tan et al., 2008; Toksöz et al., 1977, 1983). The 26 December 1939 Erzincan earthquake is the largest seismic event sourced from the master strand (Y-shear) of the dextral North Anatolian Fault System. Its epicenter is located at the junction between the NW-trending NAFS and the E–W-trending Başköy–Kandilli fault zone (Fig. 2*b*). A 360 km long surface rupture with a 12 m right-lateral and 3.5 m vertical displacements were developed during this earthquake (Koçyiğit and Tokay, 1985). In the same way, the 23 October 2011 Tabanlı (Van) earthquake is the largest seismic event of reverse faulting origin occurred in Turkey until now. The 30 km long, ENE-trending and northward dipping (55°) Everek reverse fault moved and led to the occurrence of the Tabanlı earthquake with the focal depth of 16 km, where the amount of reverse displacement was calculated to be 3.6 m by Irmak et al. (2012). However, an approximately 8 km long surface rupture with the 15 cm reverse displacement could be observed on the ground surface between Lake Van to the west and Lake Erçek to the east (Koçyiğit, 2013). The 24 November 1976 Çaldıran and the 30 October 1983 Horasan-Narman earthquakes are two other destructive seismic events of dextral to sinistral strike-slip faulting origin respectively. The 60 km long and 45°–70° N w-trending Çaldıran dextral strike-slip fault reactivated and resulted in the 24 November 1976 Çaldıran earthquake with a 55 km long surface rupture, on which the maximum dextral displacement was measured to be 3.7 m (Arpat et al., 1976). The 30 October 1983 Horasan-Narman earthquake is the first seismic event of conjugate strike-slip faulting origin. This was evidenced by the occurrence of two conjugate sets of surface ruptures of sinistral and dextral in nature. 1.2 km left-lateral and 0.6 m reverse displacements were measured on the NE-trending sinistral prominent set, while they are 50 cm and 30 cm respectively on the WNW-trending secondary set of surface rupture (Koçyiğit et al., 2001). Consequently, both the historical and instrumental period earthquakes reveal strongly the prominence of a strike-slip neotectonic regime in the EATB and near environ. In addition, focal mechanism solution diagrams of the instrumental period earthquakes fit well with the regional stress pattern, in which the major, intermediate and least principal stress axes are operating in approximately N–S, vertical and E–W directions, respectively (Fig. 2*b*).

4.1.3 Recent Seismicity: 25-28 March 2004 Tazegül and Çayköy earthquakes

An intermediate (Mw = 5.6) and shallow-focus (h = 10 km) earthquake occurred on Thursday 25 March 2004 at 21.30.50 (local time) in the near northeast of Tazegül village approximately 17 km east of Aşkale County. Three days later than the first event, a second intermediate (Mw = 5.5) and shallow-focus (h = 5 km) earthquake occurred on Sunday 28 March 2004 at 06.51.10 (local time) in the near east of Çayköy village approximately 11 km east-northeast of Aşkale County. Their epicenter sites and focal depths were reported differently by both national and international seismological centres and researchers (ERD, 2004; ETHZ, 2004; HARVARD, 2004; KOERI, 2004; Tan, 2004; Tan et al., 2008; USGS, 2004). However based on the source faults, distribution pattern and sites of aftershocks, and the nearest settlements to the epicentres, these seismic events are here named as the Tazegül and Çayköy (Aşkale–Erzurum) earthquakes respectively (Asterisks 1 and 2 in Fig. 2*a*). Both earthquakes were felt strongly over an area including City of Erzurum, Aşkale, Ilıca, Çat Counties, Kandilli Town, and a number of villages in the same area (Fig. 2*a*). Totally 9 people lost their lives, and approximately 1275 structures (residences, sheds and working places) in settlements (Küçük Geçit, Büyük Geçit, Ortabahçe, Gökçebük, Başçakmak, Gelinkaya, Çayköy, Karabıyık, Tazegül, Merdiven, Yeniköy, Güllüdere, Atlıkonak, Alaca, Tebrizcik) were heavily damaged to ruined during these two earthquakes and their numerous aftershocks (Fig. 6). The heavy damage was confined to two narrow but long zones. These are the Serçeme Çayı and the Karasu Çayı fault valleys nearby the epicentres of both seismic events (Fig. 2*a*). The most of heavily damaged to ruined settlements were constructed on both the water-saturated finer-grained sediments of the flood planes and a thick blanket of coarser-grained and loose fan-apron deposits accumulated at the foot and relatively steep slopes of active fault scarps. In fact, the water-saturated flood plains and the steep slopes of the active faults are the potential sites of both liquefaction and sudden mass-wasting processes, such as landslides, rock falls, lateral spreading and debris flows, to be triggered by the earthquakes. This was proved once more by the occurrence of 25–28 March 2004 Tazegül and Çayköy earthquakes (Doğan et al., 2004). In addition, the seismicity continued for about 6 months in a decreasing rate and main shocks of these two separate earthquakes were followed by about 600 aftershocks with magnitudes ranging from Ml/Md = 1.9 to 4.6 (Doğan et al., 2004; KOERİ, 2004; Öztürk and Bayrak, 2005). Aftershocks were concentrated in an approximately NE-trending ellipsoidal area with a long axis in and parallel to the Aşkale–Gelinkaya section of the Aşkale sinistral strike-slip fault zone (Fig. 2*a*). Both the distribution pattern of aftershocks and focal mechanism solution diagrams of these two main shocks strongly revealed that the origins of both earthquakes and related aftershocks are the Tazegül and Yarbaşı faults included in the Başköy–Kandilli and the Aşkale fault zones respectively (Fig 2*a*). Focal mechanism solution diagrams also indicate that the localized operation direction of the major principal stress axis is NNW in the earthquakes area (1 and 2 in Fig. 2a). Accordingly, the 25 and 28 March 2004 earthquakes were sourced from sinistral strike-slip faulting and sinistral strike-slip faulting with reverse component respectively (asterisks 1 and 2 in Fig. 2*a*) (Tan, 2004).

4.2 Erzurum Pull-apart Basin

This is an about 1–30 km wide, 90 km long and actively growing strike-slip depression. General trend of the basin axis varies, from west to east, E–W, NE, and NNE respectively. The Erzurum pull-apart basin is surrounded by several structural highlands such as Işıklıdağ-Dumanlıdağ to the west-southwest, Palandöken Mountains to the south, Kargapazarı Mountain to the east and Kavakdağı-Dumludağı Mountain to the north (Fig. 2*a*). The maximum reliefs between the basin floor and the highest peaks of the surrounding highlands are about 1414 m to the north and 1385 m to the south. The Erzurum pull-apart basin, which is drained by the Karasu River and its numerous transverse tributaries, has a maximum width (30 km) at its central section while it narrows and pinches out towards its west and east-northeast tips (Fig. 2*a*). The Erzurum pull-apart basin continues to be developed on the erosional surface of the Upper Cretaceous ophiolitic mélange of the Erzincan–Caucasus suture zone and the Upper Miocene–Lower Pliocene post-collisional volcanics (Erzurum Volcanics) under the control of a strike-slip neotectonic regime since Early Quaternary (2.588 Ma before present). Based on both the field geological markers and the focal mechanism solution diagrams of recent earthquakes (Fig. 2*a*) the average operation direction of the σ1 has been accepted to be N–S. In this frame the NW-trending, NE-trending, N–S-trending and the E–W trending faults are the dextral strike-slip, sinistral strike-slip, oblique-slip normal and oblique-slip reverse faults respectively (Fig. 2*b*). In the same way, fault segments gain more normal and reverse components as their strikes approach to N-S and E–W direction respectively.

In general, the Erzurum pull-apart basin is bounded by the Erzurum–Dumlu sinistral strike-slip fault zone to the east-southeast, by the Aşkale sinistral strike-slip fault zone to the north-northwest, by the Başköy–Kandilli reverse fault zone and the N–S-trending Ilıca oblique-slip normal fault set to the west (Fig. 2*a*). Each of these fault zones is described in detail below.

4.2.1 Erzurum–Dumlu fault zone

This is a totally 2–20 km wide, 146 km long and NE-trending zone of active sinistral strike-slip faulting. It is located between Yedisu Town to the southwest and Tortum County to the northeast (Fig. 1*b*). The Erzurum–Dumlu fault zone determines and controls the east-southeastern margin of the Erzurum pull-apart basin. It splays off from the WNW-trending dextral North Anatolian Fault System to the southwest and then runs for about 85 km distance in N60°E trend up to the city of Erzurum, where it bends at 40° N, results in a releasing type of bend (Erzurum releasing bend). Later on it continues again for 35 km distance in N20°E trend up to the Söğütlü settlement (near south of Tortum County), where it rebends at 25° S, runs for about 25 km distance in N45°E trend, meets with the E–W-trending Kamışözü reverse fault and disappears around Karapınar village outside the study area to the further northeast (Fig. 1*b*). The Erzurum releasing bend is the epicentre site of a destructive earthquake, the 2nd June 1859 historical earthquake of Io = IX, (Fig. 2*a*). The 25 km long northeastern and the 66 km long southwestern parts of the Erzurum–Dumlu fault zone are outside the study area, while its 55 km long central section (Yağmurcuk–Şenyurt section) is included in the study area (Fig. 2*a*). It was examined in detail in the frame of this study. Based on the trends of faults, the Erzurum–Dumlu fault zone is divided into two main sections. These are the N60°E-trending western section (Erzurum section) (Fig. 2*a*) and the N20°E-trending eastern section (Dumlu section) (Fig. 2*a*). The fault segments comprising the Dumlu section of the fault zone have much more normal-slip component owing to the proximity between the trends of faults and the operation direction of the σ1.

Both sections of the Erzurum–Dumlu fault zone consist of numerous fault segments of dissimilar size, trend and type. These are the NE-trending sinistral strike-slip faults, NW-trending dextral strike-slip faults, NNE-trending sinistral strike-slip faults with considerable amount of normal-slip component, the N–S-trend-

Fig. 6. General view of the Küçük Geçit village ruined by the 28 March 2004 Çayköyü (Aşkale–Erzurum) earthquake (view to west).

ing oblique-slip normal faults and the E–W-trending reverse faults (Fig. 2*a*). However the NE-to NNE-trending sinistral strike-slip fault segments are most prominent. They are parallel and semi-parallel, closely-to moderately spaced (0.1–4 km) and diverse-sized (0.1–44 km) (Fig. 2*a*). The Quaternary basin fills and older rocks are cut, displaced in both vertical (up to 0.3 km) to lateral (up to 8 km) directions, and then juxtaposed tectonically by the fault segments comprising the Erzurum–Dumlu fault zone traces (Fig. 7*a, b, c*). Sudden break in slope, triangular facets, deflected to offset drainage system (e.g., Karasu River, Tekederesi, and Köşk streams), fault-parallel aligned alluvial fans to fissure eruptions, faulted-, uplifted-, dissected- and fault-suspended fan-apron deposits (fault terraces), basinward–facing steep scarps (Figs. 8*a* and 8*b*), faulted superimposed alluvial fans, pressure ridges of Quaternary basin fill (Figs. 7*a* and 7*c*), tectonic juxtaposition of Quaternary basin fill with the pre-Quaternary rocks (mostly the Erzurum Volcanics of late Miocene-early Pliocene age), crushed to brecciated strips of rocks exposed along the traces of fault segments and well-developed to preserved slickensides (S.1, S.2, S.3 in Fig. 2*a*) are common morphotectonic to fault plane-related field criteria used for recognition of fault segments. Stereographic plot of slip-plane data on the Schmidth lower hemisphere net indicates that the southern margin-boundary faults are mostly sinistral strike-slip fault in nature, and the Erzurum pull-apart basin has been extending in approximately ENE direction (Fig. 9). The most prominent and active fault segments comprising the Erzurum–Dumlu fault zone are, in turn, the Erzurum, Değirmendere, Palandöken, Börekli, Kümbet, Karnıyarık, Gedikkaya, Tekederesi, Kösemehmet, Güzeloba, and Köşk faults (Fig. 2*a*). The destructive historical earthquakes, offset drainage system, and normal to reverse type of outcrop-scale faults, which cut across and offset the Quaternary boulder-block conglomerate (Fig. 10*a* and S.4 in Fig. 2*a*), are diagnostic field and seismic data revealing the activeness of these faults. Both the Köşk stream and the Tekederesi stream are controlled and offset (up to 8 km) in left lateral direction by the Köşk and Tekederesi faults respectively (Fig. 2*a*). The second June 1859 Erzurum historical earthquake of Io = IX was sourced from the Değirmenderesi fault (Fig. 2*a*). However the volume of the present paper is no suitable for description of whole of fault segments. For this reason, only master fault (the Erzurum fault) of the fault zone is described in more detail below.

4.2.1.1 Erzurum fault (Y-shear)

It is a NE-trending and totally 60 km long sinistral strike-slip fault located between Şenyurt settlement to the northeast and near west of Yağmurcuk village to the southwest (Fig. 2*a*). It displays a curvi-linear trace. It is cut, displaced in dextral direction and divided into several segments by the NW-trending dextral strike-slip faults in places. In addition, the trace of the Erzurum fault is also buried by thick Holocene sediments of the young superimposed fans in places. However its exposed parts bifurcate into two or more sub-branches and then rejoin and rebifurcate resulting in a series of pressure ridges exposed along its whole length. Two of the well-developed ones are the Harput and the Çiğdemtepe pressure ridges (Figs. 7*a, c* and 10*b*). Both the Quaternary fluvial conglomerates and the underlying sedimentary sequence of the Pliocene Gelinkaya Formation have been squeezed, fractured, uplifted and tilted into sub-vertical position along both the Harput and Çiğdemtepe pressure ridges (Fig. 10*c*). The Harput pressure ridge occurs at the city centre of Erzurum crossed entirely by the active fault segments (Figs. 2*a* and 10*b, c*). In addition, the city of Erzurum with very high population over 400,000 is also located on a thick and unconsolidated fan-apron deposits of Quaternary age, i.e., people in this city are open to a huge risk of a large destructive earthquake to be sourced from the Erzurum fault (Fig. 10*b*). A matter of fact that the ski jumping facilities constructed three years ago just on this pressure ridge have been collapsed and ruined owing to a landslide triggered by motion on its margin-boundary fault (the Erzurum fault). The longest segment of the Erzurum fault is about 44 km in length, and the magnitude of the peak earthquake to be sourced from the Erzurum fault is Mw = 6.98 (Wells and Coppersmith, 1994).

4.2.2 Aşkale fault zone

This is a totally 2–6 km wide, 140 km long and NE-trending sinistral strike-slip fault zone located between Tanyeri Town to the southwest and the Söğütyanı Village to the northeast (Fig. 1*b*). The Aşkale fault zone splays off from the dextral North Anatolian Fault System around the eastern tip of the Erzincan pull-apart basin to the southwest (Fig. 1*b*) and then runs in northeast direction across the various settlements of Çamlıca, Esenyurt, Akyurt, Tercan, Yaylacık, Gümüşseren, Aşkale, Küçük Geçit, Çayköyü, Gelinkaya, Uzunyayla, Kırmızıtaş, Kırkgöze, and Söğütyanı, where it meets with the Erzurum–Dumlu fault zone and terminates (Fig. 2*a*). The 55 km long southwestern section (Tercan–Tanyeri section) of the Aşkale fault zone is outside the study area while its remaining 85 km long central to northeastern section (the Aşkale–Söğütyanı section) is included in the study area. The Aşkale–Söğütyanı section of the Aşkale fault zone determines and controls the northwestern margin of the Erzurum pull-apart basin (Fig. 2*a*). The Aşkale fault zone consists of numerous fault segments of dissimilar size, trend and type. The NE-trending sinistral strike-slip fault segments are most prominent. They are parallel and semi-parallel, closely-to moderately-spaced (150 m–3 km) and diverse-sized (0.2–40 km) struc-

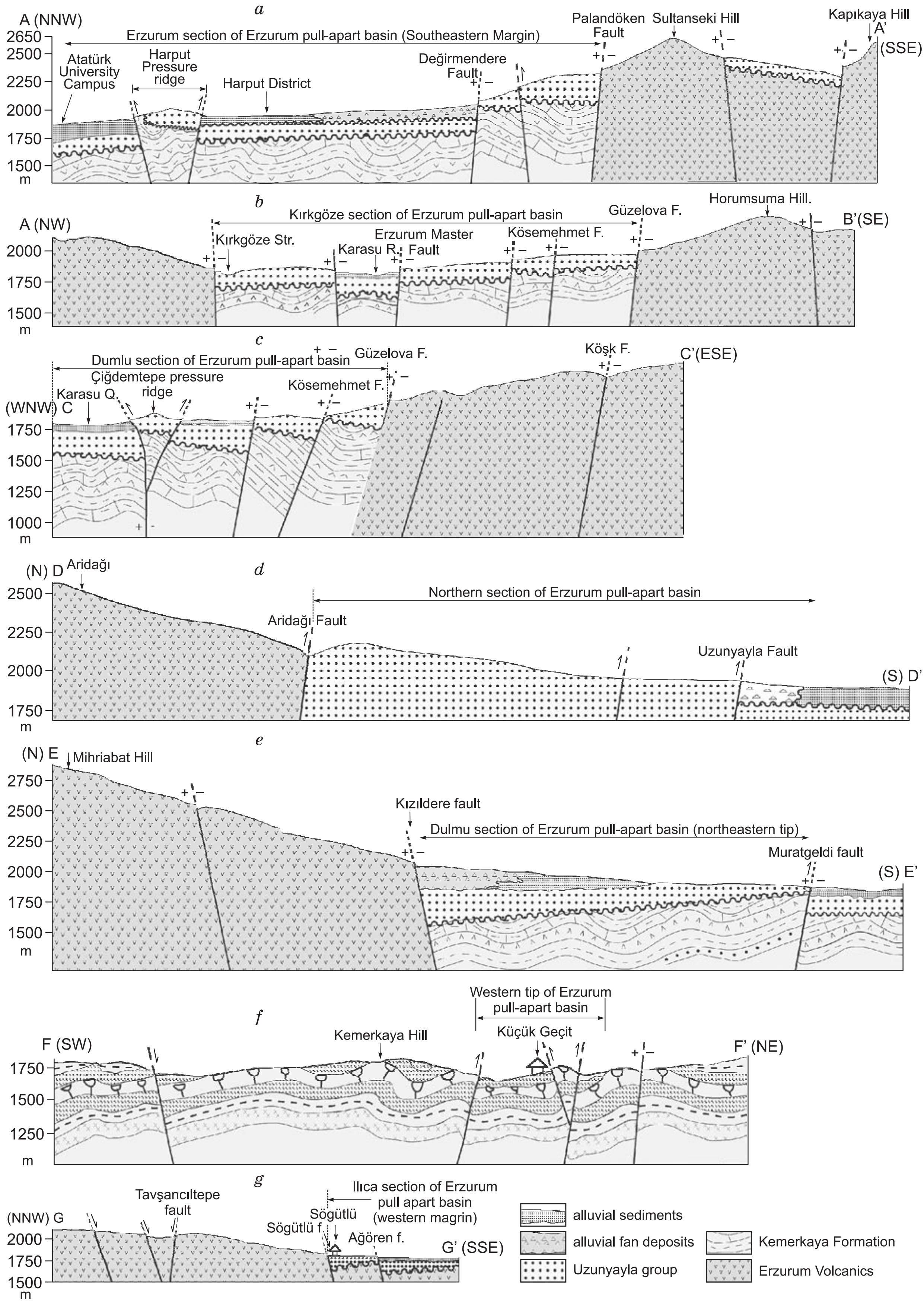
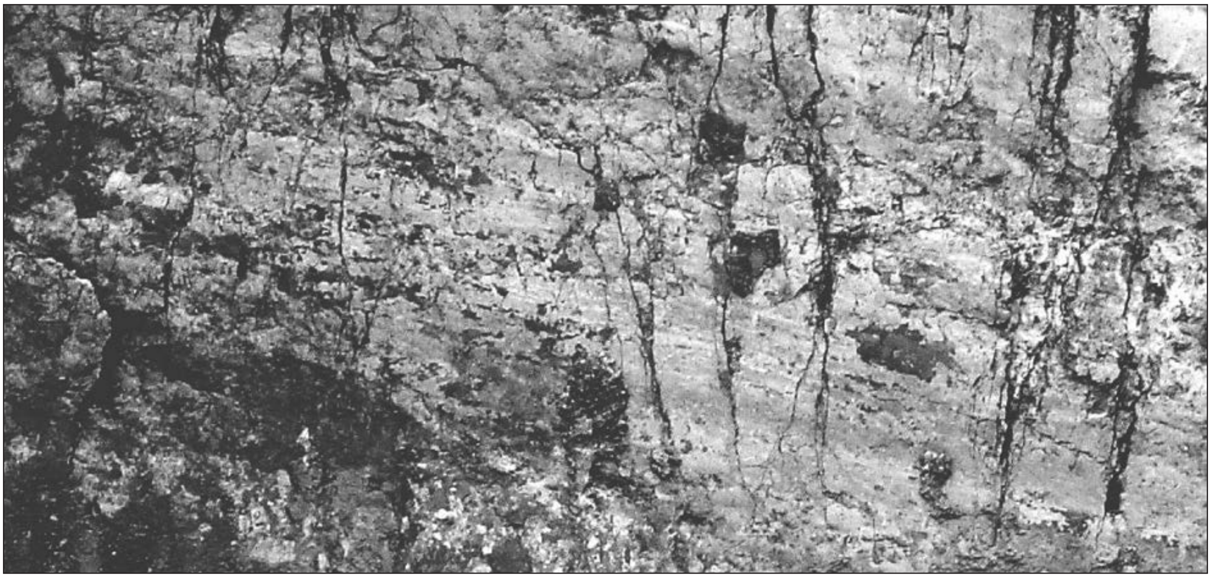


Fig. 7. Various geological cross-sections showing the structure of the Erzurum pull-apart basin. See the Fig. 2 for the sites of geological cross sections.

Fig. 8. ***a*****, General view of the Değirmendere fault scarp (F–F) and a series of settlements (Yıldızkent, Evren, Değirmendere, Tuzcu, Tepeköy) located on its northern down-thrown block (view to southwest);** ***b*****, general view of both the Güzeloba (F–F) and Kösemehmet (F1–F1) fault scarp (view to southeast).**

tural fault segments (Figs. 2*a* and 5). Quaternary basin fills and older rocks are cut, displaced in both vertical (up to 0.5 km) and lateral (up to 22 km) directions and juxtaposed tectonically by these fault segments (Figs. 7*d*, *e*, and *f*). Both the morphotectonic and fault plane-related field criteria used for recognition of fault segments comprising the Aşkale fault zone are same as those of the Erzurum–Dumlu fault zone. Therefore they have not been repeated once more here. However both the historical and recent earthquakes (Figs 2*a* and 11), offset drainage system (Fig. 11), and the faulted superimposed alluvial fans (Fig. 5) are the most diagnostic field and seismic data revealing the activeness of these faults. The most prominent and active fault segments are divided into four groups based on the trends and types. These are the NE-trending strike slip faults (Kırkgöze, Taşköprü, Akdere, Kızıldere, Yeşilyayla, Serçeme, Gelinkakya, Yarbaşı, Gökçebük, Aşkale, Tercan, and Akyurt faults), NW-trending dextral strike-slip faults (Akdağ, İkiztepeler, Yerlisu and Kemerkaya faults), N–S-trending oblique-slip normal faults (Keçikaya, Eskiyayla, Karahan, and Aktoprak faults) and the E–W-trending reverse faults (Muratgeldi, Arıdağı, Uzunyayla, and the Umudum faults) (Figs. 2*a* and 5). The north-westward flowing Karasu River is bent towards southwest and then offset for about 7 km distance in left lateral direction after it entered into the NE-trending Aşkale fault zone to the near east of Aşkale County (X–Y in Fig. 2*a*). In the same way, the northwestward flowing Tuzla Çayı is also bent towards southwest at the point T in Fig. 11, flows for 10 km distance in the same direction, meets with the southeastward flowing Karasu River, takes the name of Fırat River and then continues to flow up to Yollarüstü settlement (outside the study area) under the control of the Tercan and Akyurt fault segments of the Aşkale fault zone, i.e., both the Tuzla Çayı and Fırat Rivers altogether are offset for about 22 km in left lateral direction. Around the Tercan area, the NW-trending Çayırlı fault segments, NE-trending Aşkale fault segments and the N–S-trending oblique-slip normal fault segments intersect to each other. Thus they lead to the locking of motion on fault segments of dissimilar nature and result in a seismic gap with a long-term accumulation of elastic strain energy. This was proved by the occurrence of the 1458 Kızılca (Tercan) destructive earthquake of Io = IX (Table 1). The 28 March 2004 Aşkale earthquake of Mw = 5.5 was sourced from the Yarbaşı fault (asterisk 2 in Fig. 2*a*) and caused to the reactivation of several structural fault segments, such as the Aşkale, Gökçebük, Serçeme, and Gelinkaya faults (Fig. 12a). This was indicated by both the NE-trending and faults-parallel linear distribution pattern of aftershocks of the 28 March *a*



b

№	Strike	Dip amount	Rake	Type
1	29	48W	07S	S
2	36	46W	08S	S
3	46	48W	06S	S
4	30	44W	18S	S
5	28	47W	14S	S
6	32	49W	11S	S
7	300	88N	30E	D
8	302	80N	26E	D
9	314	75N	40E	D
10	316	79N	37E	D
11	303	85N	43E	D
12	320	83N	38E	D
13	319	79N	42E	D

c

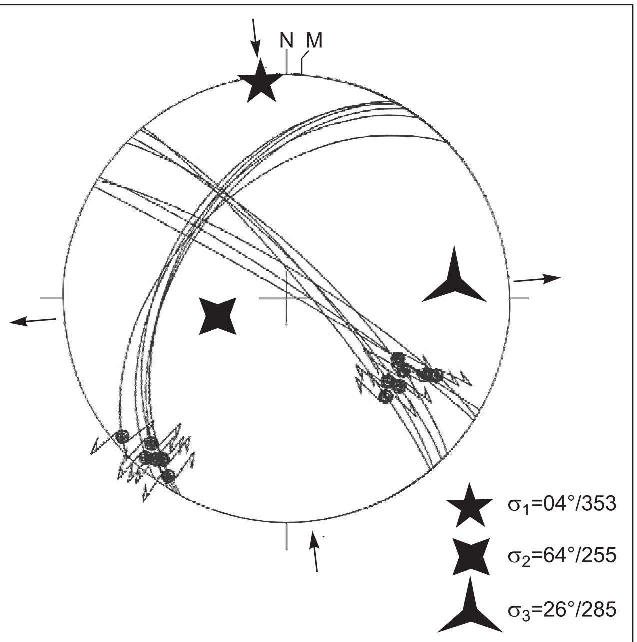


Fig. 9. ***a*, Close-up view of the Güzelova Fault slickenside; *b*, slip-plane data measured at S.2 and S.3 in Fig. 2; *c*, stereographic plot of slip-plane data on the Schmidt's lower hemisphere net (large black arrows show local operation direction of the greatest principal stress: σ1).**

2004 Aşkale earthquake (Öztürk and Bayrak, 2005), and a series of ruined settlements, such as Küçük Geçit, Çayköyü, Yarbaşı, Gökçebük, Gelinkaya, Yoncalık, and Eskipolat villages, during the same earthquake (Figs. 2*a* and 6).

The deflected to offset drainage system and the faulted superimposed alluvial fans to fan-apron deposits are exposed well around Kırmızıtaş and Kırkgöze settlements in the northeast section of the Aşkale fault zone (Figs. 5 and 12*b*). In this area, two significant transverse tributaries of the Karasu River are the Kızıldere and Kırkgöze streams. They emanate from the peak of the Mihriabat Hill (2851 m above sea level) and flow towards the basin in down-slope direction. Later on these tributaries are deflected to offset in left lateral direction and then meet with the Karasu River flowing inside the depocentre of the Erzurum pull-apart basin. A series of older and younger alluvial fans to fan-aprons have been developed by the accumulation of sediments transported by these tributaries (FFA in the Fig. 5). In the same area the Kızıldere, Kırkgöze, and Akdağ fault seg-

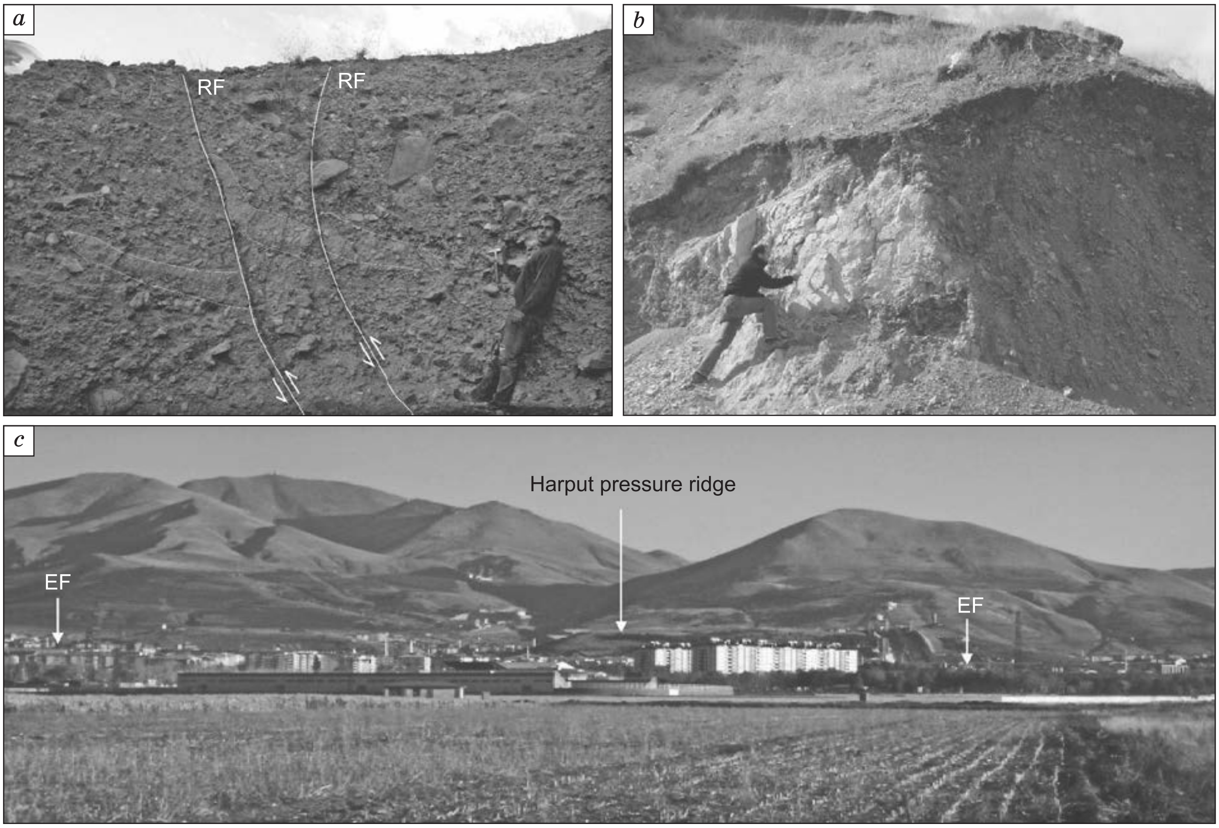


Fig. 10. *a*, Close-up view of an outcrop-scaled reverse fault cutting across and offsetting the Quaternary boulder-block conglomerates (S.4 in Fig. 2*a*); *b*, close-up view of Quaternary fluvial conglomerates tilted up to sub-vertical position, and fault slickenside at S.1 in Fig. 2*a*; *c*, general view of the Harput pressure ridges bounded by the Erzurum fault (EF), and dense construction on and around them (the city of Erzurum).

ments are the margin-boundary faults of the Erzurum pull-apart basin. They cut and juxtapose tectonically the Upper Miocene–Pliocene Erzurum Volcanics with the Quaternary basin fill, while other faults (Kırrmızıtaş, Akdere, Taşköprü, Gülpınar, İkiztepeler, and Muratgeldi faults) cut, uplift, dissect and deform the younger basin fill (Figs. 5 and 7*e*). Consequently whole of these morphotectonic features and the fault-parallel aligned hot water spring occurrences altogether reveal both the existence and activeness of these fault segments (Figs. 5 and 12*b*). The longest (40 km) structural fault segment of the Aşkale fault zone is the Tercan fault (Fig. 11). Based on its length, the magnitude of the peak earthquake to be sourced from the Aşkale fault zone is Mw = 6.95 (Wells and Coppersmith, 1994).

4.2.3 Başköy-Kandilli fault zone

This is a totally 5–13 km wide, 160 km long and E–W-trending active zone of deformation located between Koçyatağı village to the west and Ilıca County to the east (Fig. 1b). The Başköy–Kandilli fault zone splays off from the North Anatolian Fault System around Koçyatağı village, which is the epicentre site of the largest 28 December 1939 Erzincan earthquake of Mw = 8.0, to the west and outside the study area. Later on it runs eastwards across a series of settlements in the size of village, town and counties, such as Başköy, Aşkale, Kandilli, and Ilıca to the east (Figs. 1*b* and 2*a*). The 52 km long eastern section (Aşkale–Ilıca section) of the fault zone is included in the study area while remaining 108 km long western section (Başköy–Koçyatağı section) is outside the study area. The Aşkale–Ilıca section, which intersects with the Aşkale fault zone around Aşkale County, determines and controls southern margin of the western part of the Erzurum pull-apart basin (Fig. 2*a*). The Başköy–Kandilli fault zone consists of numerous fault segments of dissimilar size, trend and type. The E–W-trending reverse faults with considerable amount of strike-slip components and the N–S-trending oblique-slip normal faults (e.g., Ilıca normal fault set) are much more prominent with respect to other fault segments (Fig. 2*a*). Fault segments are parallel and semi-parallel, closely-to widely-spaced (0.3 km 8 km) and

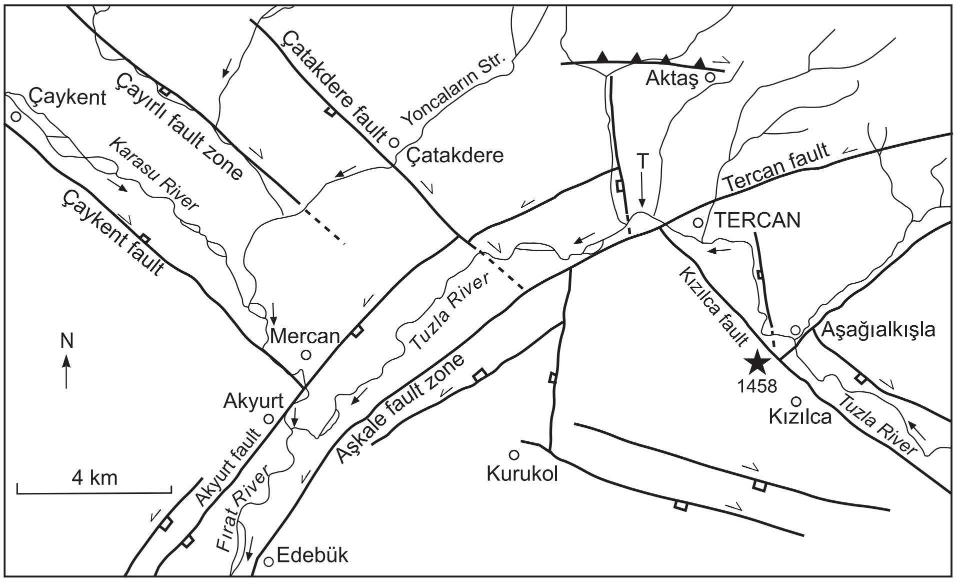


Fig. 11. Fault map of the Tercan area. The Tuzla River enters into the Başkale fault zone at point T and then is offset in left-lateral direction.

vary from 1 km to 36 km in size. They cut both the Quaternary basin fills and older rocks along their traces and displace them in both vertical (up to 0.5 km) and lateral directions (Figs. 2*a* and 7*g*). Both the morphotectonic and fault plane-related field criteria used for recognition of fault segments are same as those of both the Erzurum–Dumlu and Aşkale fault zones. The most prominent and active fault segments comprising the Başköy–Kandilli fault zone are, from west to east, the Akdağ (36 km), Başköy (24), Ardıçyayla (32), Çevlikdüzü (34 km), Meyramdağı (29), Çamoğlu (17), Atlıkonak (22), Yenice (31), Kandilli (21), and Alaca (10 km) faults. The first three fault segments are exposed to the west and outside the study area while remaining fault segments are included in the study area (Fig. 2*a*). The volume of the present paper is no suitable for description of whole of fault segments. For this reason the most diagnostic ones of them are explained in more detail below.

4.2.3.1 Yenice fault

This is a WNW-trending reverse fault with considerable amount of strike-slip component. It is located between Güllüce village to the west and Özbek settlement to the east (Fig. 2*a*). The trace of the Yenice fault is curvi-linear in shape and bifurcates into several sub-branches at its both eastern and western tips. The Yenice fault and its sub-branches cut and displace both the Miocene-Pliocene Erzurum Volcanics and juxtapose tectonically them with the Quaternary fill of the Erzurum pull-apart basin (Fig. 2*a*).

4.2.3.2 Atlıkonak, Kandilli and Alaca faults

These are the southern margin boundary faults of the western section of the Erzurum pull-apart basin. They are located in the area between Kandilli Town to the west and Alcı Hill to Ilıca County to the east. An approximately 27 km long part of the Karasu River is controlled mostly by these three faults. The Atlıkonak fault is an about 22 km long and WNW-trending reverse fault with considerable amount of strike-slip component. It displays a curvi-linear trace, basinward-facing steep fault scarp and a pressure ridge at its western tip (Fig. 2*a*). The well-developed slickenside, steeply sloping fault scarp and the hanging valley on its upthrown southern block are diagnostic field criteria for recognition of the Atlıkonak fault (Fig. 12*c*). Both the Erzurum Volcanics and the fluvio-lalcustrine sedimentary sequence of Pliocene age are cut, displaced in vertical direction and then juxtaposed tectonically with the Quaternary fill of the Erzurum pull-apart basin. The Kandilli fault is an approximately 21 km long and ENE-trending reverse fault with a considerable strike-slip component. It is located between Kandilli Town to the west and Ilıca County to the east. The Kandilli fault controls southern slope of the Karasu River valley along its trace. A series of thermal springs occur at the intersection of the Kandilli fault and the N-S-trending Ilıca oblique-slip normal fault set (Fig. 2*a*). The Alaca fault is an about 10 km long and ENE-trending sinistral-strike-slip fault with considerable reverse component. The Alaca fault is located between Tazegül to the southwest and Çiğdemli to the northeast and controls northern slope of the Karasu River (Fig. 2*a*). The fluvio-lacustrine sedimentary sequence of Pliocene age is cut, displaced in vertical to lateral directions and juxtaposed tectonically with the Quaternary fill of the Erzurum pull-apart basin.

4.2.3.3 Ilıca fault set

This is a 4 km wide, 12 km long and approximately N–S-trending active zone of oblique-slip normal faulting. The Ilıca fault set is located between Sakalıkesik village to the south and Ilıca County to the north (Fig. 2a). It determines and controls western margin of the Erzurum pull-apart basin. The Ilıca fault set consists mostly of N–S- to NNE-trending, closely-spaced (0.8–1.7 km) and diverse-sized (0.3–7.5 km) oblique-slip normal fault segments. They cut across the Upper Miocene-Lower Pliocene Erzurum Volcanics, the Pliocene fluvio-lacustrine sedimentary sequence (Gelinkaya Formation), the Quaternary fill of the Erzurum pull-apart basin and displace them in vertical direction and then juxtapose tectonically these rock units with to each other. The most active and longer two segments of the Ilıca fault set are the 7.5 km long Söğütlü and Ağören faults (Fig. 2*a*).

A moderate and shallow-focus seismic event (the 25 March 2004 Tazegül earthquake of Mw = 5.6) (Table 2) occurred in the Aşkale–Ilıca section of the Başköy–Kandilli fault zone. It was sourced from the NE-trending Tazegül sinistral strike-slip fault (Asteriks-1 in Fig. 2*a*). Above-mentioned three faults (Atlıkonak, Kandilli, and Alaca faults) and two segments (the Söğütlü and Ağören faults) of the Ilıca fault set were reactivated and a number of settlements (Karabıyık, Tazegül, Merdiven, Ortabahçe, Kandilli, Atlıkonak, Alca, Tebrizcik, Ağören, and Söğütlü) located on both the water-saturated loose sediments and these faults were heavily damaged and ruined. Consequently most of fault segments comprising the Başköy–Kandilli fault zone are active. The longest active fault segment of the fault zone is the 36 km long Akdağ fault located to the near

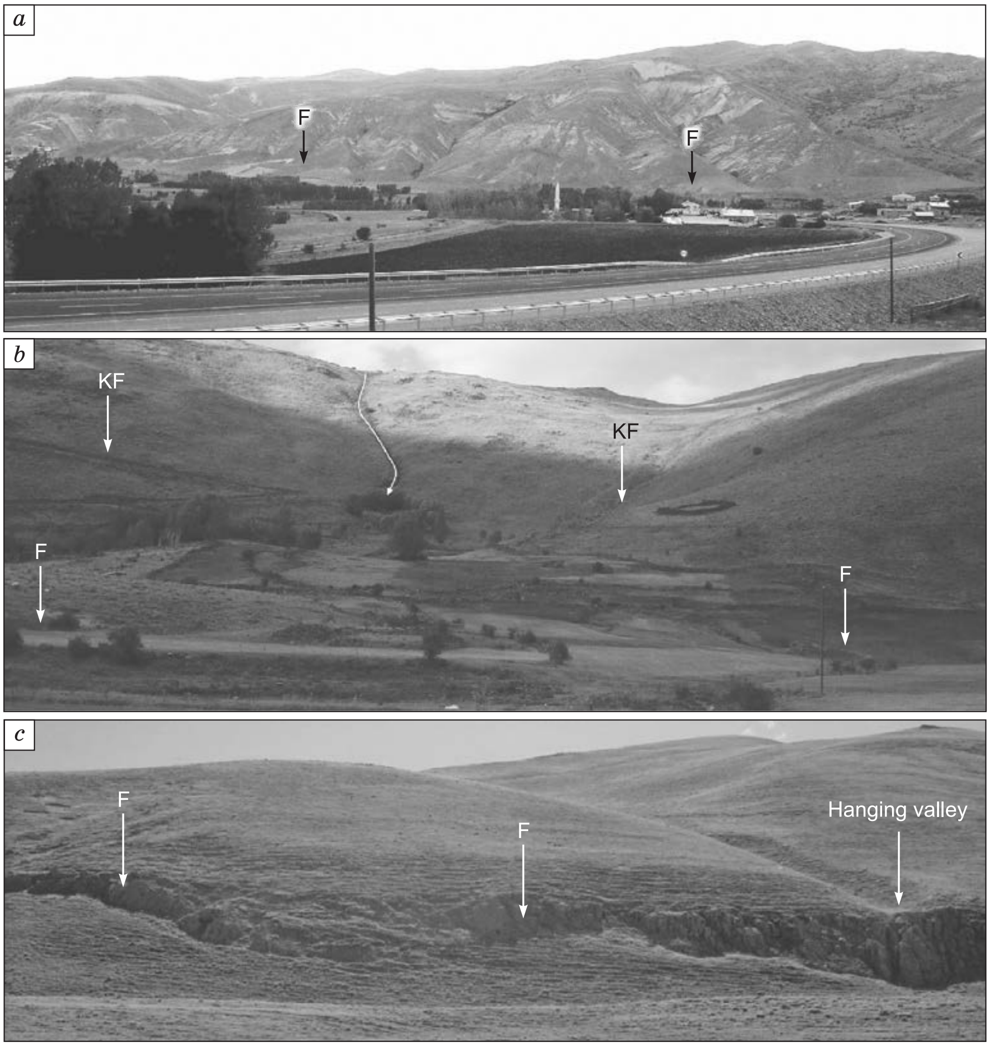


Fig. 12. *a*, General view of the Gökçebük fault trace (F–F) and scarp (view to NNW); *b*, general view of both the stream deflected into "S-shape" and the alluvial fan cut across and deformed in a direction parallel to the general trend of the Kırkgöze faults (KF, F–F) (view to north); *c*, general view of the Atlıkonak fault scarp (F) and a hanging valley (view to south).

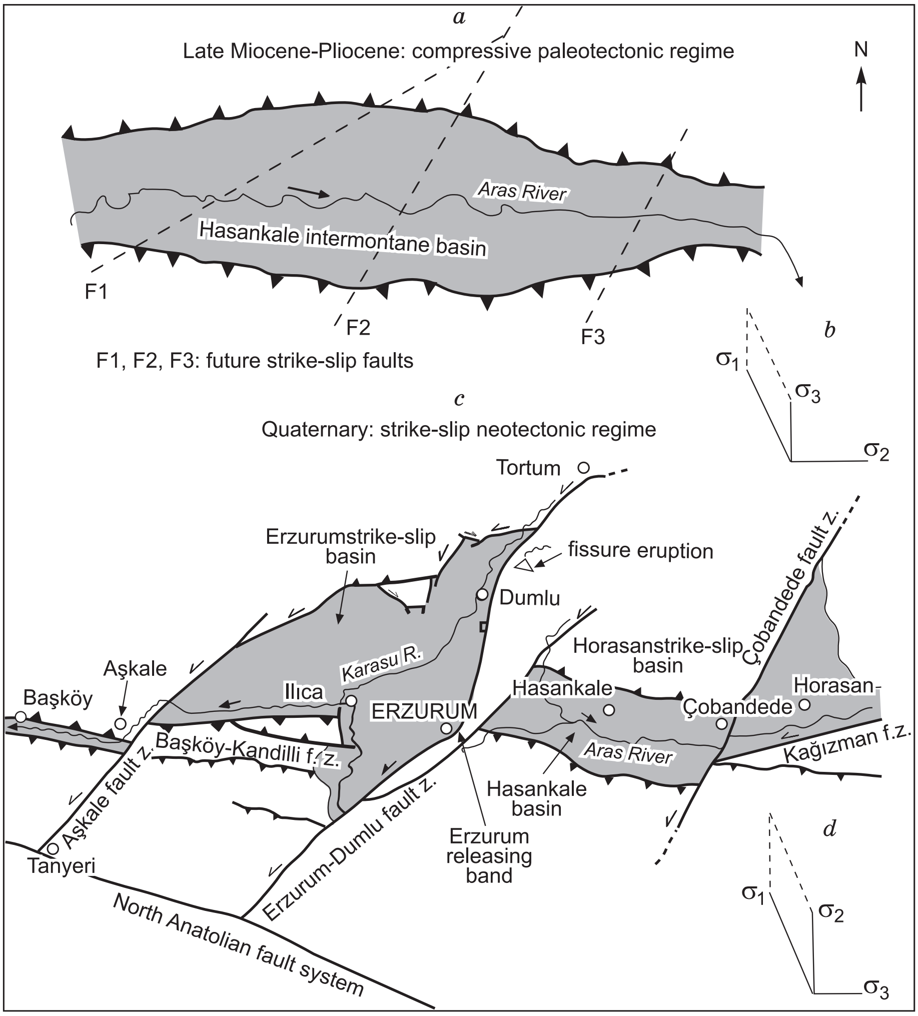


Fig. 13. Sketched maps depicting evolutionary history of the Erzurum pull-apart basin.

west and outside the study area. Based on the length of the active fault segment, the magnitude of the peak earthquake to be sourced from the Başköy–Kandilli fault zone is Mw = 6.88 (Wells and Coppersmith, 1994)

5. DISCUSSION

During late Early Miocene, there was a broad and E–W trending sea way between the southerly located Arabian passive margin and the northerly located Eurasian active margin in the recent site of the east-southeastern Turkey. This was the Bitlis Ocean (southern branch of Neo-Tethys). It was extending up to Erzurum to the further north. The marine reefal build-ups comprising the lower section of the Kemerkaya Formation of late Early Miocene age were deposited in the continental shelf of this oceanic realm. This sea way persisted to appear until late Middle Miocene (Serravalian) and then was closed and demised entirely by the continent-continent collision and suturing of the Arabian plate with the Eurasian plate (Dewey et al., 1986; Şengör and Yılmaz, 1981). Owing to the post-collisional intracontinental convergence along the Lesser Caucasian and the Bitlis Suture zones, the intervening area was squeezed up as a 2 km-high plateau, namely the East Anatolian-Iranian plateau, (Şengör and Kidd, 1979). The intracontnental convergence and the N–S-directed compressional-contractional paleotectonic regime remained until the end of Early Pliocene along the Bitlis–Zagros suture zone and adjacent areas. This is indicated by the late Pliocene regional erosional surface and related angular unconformity separating the intensely deformed paleotectonic units from the nearly flat-lying neotectonic units (Koçyiğit et al., 2001). This older tectonic regime, in which the major principal stress axis (σ1) was operating in an approximately N–S direction while the least principal stress axis (σ3) was acting in a vertical direction, was being dominated by the folds with E–W-trending axes, north- to south-vergent thrust and reverse faults, and the intermontane or ramp basins with the E–W-trending long axes (Şaroğlu and Yılmaz, 1986). The most prominent one of these basins was the Erzurum–Hasankale intermontane basin located between Horasan to the east and Aşkale to the west (Fig. 13*a*). The ancestral Erzurum and the Hasankale depressions were once joined to each other as the unique intermontane basin during the Miocene–early Pliocene paleotectonic period. It was being bounded by a series of E–W-trending and north to south-vergent reverse faults along its both margins, and drained by the estward flowing ancestral Aras River. In this frame the most of the E–W trending reverse faults comprising the Başkale–Kandilli and Aşkale fault zones are inherited from the paleotectonic period and they were the margin-boundary faults of the ancestral Erzurum–Hasankale intermontane basin. The existence of the E–W-trending Erzurum–Hasankale intermontane basin is indicated by: (a) the occurrence of two formations (Kemerkaya and Gelinkaya formations) with same litho-and biofacies, sedimentary structures, age and depositional settings in both the Erzurum and Hasankale basins, (b) the sediments comprising the Gelinkaya Formation have been transported from west to east based on the sedimentary structures, such as the delta and cross-bedded structures (Fig. 4), included in this formation, (c) whereas recent Erzurum and Hasankale basins are being drained in opposite directions by the westward flowing Karasu River and the eastward flowing Aras River, respectively in the Quaternary neotectonic period (Fig. 13*b*).

Starting from Early Quaternary onwards, the southern frontal part of the Eurasian plate was fragmented and divided into several mega- and numerous micro-blocks resulting in five main structures. These are the dextral North Anatolian Fault System (NAFS), the sinistral East Anatolian Fault System (EAFS), the Northeast Anatolian sinistral strike-slip fault system (combination of both the Kelkit–Çoruh and the Borjomi–Kasbeg fault zones), the Anatolian platelet and the East Anatolian–Iranian Plateau (Fig. 1). Along the NAFS and the EAFS, the Anatolian platelet started to escape in WSW direction onto the oceanic lithosphere of the African plate (Hempton, 1987; Koçyiğit and Beyhan, 1998). Conversely, the western half of the East Anatolian–Iranian Plateau (EATB) could not move easily in east direction as much as the Anatolian platelet owing to lack of a strike-slip fault system along its southern margin (Fig. 1). The EATB was shortened excessively in N-S direction and uplifted which increased the gravity force. It led to an inversion in the stress distribution and the emergence of a new tectonic regime (the strike-slip faulting-dominated neotectonic regime) in the EATB (Tapponnier, 1979). Thus, the earlier real compressional–contractional tectonic regime was replaced by the strike-slip faulting-dominated neotectonic regime during Early Quaternary (Koçyiğit et al. 2001; Çolak et al., 2012). This new tectonic regime is being dominated by the well-developed strike-slip faulting pattern and related strike-slip basins such as the Erzurum pull-apart basin (Fig. 2). The strike-slip faulting pattern is composed of NW- and NE-trending strike-slip faults, E–W- trending thrust to reverse faults, approximately N–S trending oblique-slip normal faults and /or fissures running along the summits of Quaternary volcanoes (Fig. 1b) (Dhont and Chorowicz, 2006; Gülen, 1984; Jackson, 1992; Koçyiğit, 1985a, 1985b; Koçyiğit et al., 2001; McClusky et al., 2000; Rebai et al., 1993; Reilinger et al., 1997). In the same way, the EATB itself was also started to be deformed internally and broken down into a number of smaller blocks by the newly forming NE-trending sinistral and NW-trending dextral strike-slip faults and fault zones such as the Aşkale (AFZ), Erzurum–Dumlu (EDFZ), Çobandede (ÇFZ), Narman (NFZ), Kura (KFZ), Kağızman (KF), Digor (DF) and Başkale (BFZ) sinistral strike-slip fault zones; the Pambak-Sevan (PSFZ), Iğdır (IF), Balıkgölü (BGF), Tutak-Çaldıran (TÇF), Karayazı-Erciş (KEFZ), Salmas (SFZ) and the Yüksekova (YFZ) dextral strike-slip fault zones (Fig. 1) (Arpat et al., 1976; Şaroğlu et al., 1984; Koçyiğit, 1985a, 1985b; Koçyiğit et al., 1985; Şaroğlu and Yılmaz, 1986; Şaroğlu et al., 1987; Cisternas et al., 1989; Rebai et al., 1993; Koçyiğit et al., 2001; Dhont and Chorowicz, 2006). Accordingly, the E–W-trending ancestral Erzurum–Hasankale unique intermontane basin was also deformed and divided into three depressions such as the NE-trending Horasan, E–W-trending Hasankale and again NE-trending Erzurum depressions by the development of the NE-trending Aşkale, Erzurum–Dumlu and Çobandede sinistral strike-slip fault zones. They have been continuing to develop as separate pull-apart basins under the control of strike-slip neotectonic regime and related faults in the present (Figs. 2a and 13b). The most prominent one of these three depressions is the Erzurum pull-apart basin. It is controlled by the Ilıca oblique-slip normal fault set along its western margin (Figs. 2a and 7g) while the Erzurum–Dumlu fault zone determines and controls its eastern margin. A releasing type of bend (Erzurum releasing bend) occurs around the city of Erzurum along the general trend of this fault zone. After this releasing bend fault segments comprising the north-northeastern section of the Erzurum–Dumlu fault zone begin to gain considerable amount of normal component (Figs. 2a and 13b). For these reasons, the Erzurum pull-apart basin is being widened in approximately E–W direction.

As has been indicated by both the historical and recent destructive earthquakes (Tables 1 and 2), the seismicity of the EATB, which also includes the Erzurum pull-apart basin and near environ, is very high. Foci of earthquakes occurred in the EATB are concentrated mostly in the uppermost 10 km thick brittle part of the crust while their limited amount is distributed up to the depths of 60 km where the ground is underlain by thick metamorphic massifs such as the Bitlis-Pötürge Massif along the Bitlis suture zone (Şengör et al., 2008) and the Erzincan-Pulur metamorphics along the Erzincan–Caucasus suture zone (Bektaş et al., 1984; Koçyiğit, 1991). This implies to that the strike-slip neotectonic regime and related deformation are confined into the upper most and approximately 35-40 km thick and relatively brittle part of the crust. In contrast to the strike-slip neotectonic regime, Göğüş and Pysklywec (2008) suggested that the eastern Anatolian plateau is the site of lithospheric thinning, plateau uplift, heating and syn-convergent extension resulted from the delamination of the mantle lithosphere, i.e., the EATB is the site of extension. They have also reported that the Hasankale, Kağızman, Tuzluca, Hınıs, Karlıova, and Muş basins are the E–W-trending and normal fault-controlled extensional basins developed as a natural response to the syn-convergent extension. In contrast to the idea of these authors, there is a big discrepancy between the site of extension they suggested and the nature of structures and style of deformation patterns observed in the eastern Anatolian plateau (Dhont and Chorowicz, 2006; Koçyiğit et al. 2001), because, the local and shallow-seated extension in the EATB is related to the strike-slip tectonic regime, not consistent with the structures observed in this region. The EATB is shaped by en echelon folds, E–W trending thrust to reverse faults, N-S trending extensional features such as normal faults and fissures, NE- and NW-trending strike-slip faults and related pull-apart basins, i.e., the Hasankale, Kağızman, Tuzluca, Hınıs, Karlıova and Muş basins are strike-slip fault-controlled pull-apart basins not normal fault-controlled grabens. In addition, the heating and syn-convergent extension resulted from the delamination of the mantle lithosphere are sub-crustal processes taking place in a squashy zone at the depths of approximately 40 to 60 km (Şengör et al., 2008). Consequently both the extensional and contractional features observed in the EATB reveal strongly the predominance of a strike-slip neotectonic regime rather than tensional tectonic regime. This is also indicated by the fault plane solutions of moderate to large destructive earthquakes of both the strike-slip faulting and thrusting origin such as the 1962 Iğdır, 1966 Varto, 1975 Lice, 1976 Çaldıran, 1983 Horasan-Narman, 1988 Spitak, 2000 Altınsaç (Van), 2004 Aşkale (Erzurum), 2005 Başkale, and very recent 2011 Tabanlı (Van) earthquakes (ERD, 2011; Eyidoğan et al., 1991; KOERI, 2011; McKenzie, 1972; Örgülü et al., 2003; Philip et al., 1992; Tan, 2004; Tan et al., 2008; Tchalenko, 1977; Toksöz et al., 1977, 1983; Wallace, 1968).

6. CONCLUSIONS

Based on both the foregoing presented data and discussion the followings can be concluded and suggested.

1. In terms of field geological mapping carried out in the Erzurum region three fault zones were identified, mapped and named separately. These are the NE-trending Aşkale, Erzurum–Dumlu and the E–W-trending Başköy–Kandilli fault zones. Their combination and the intervening basin (the Erzurum pull-apart basin) indicate a strike-slip faulting pattern.

2. The Erzurum pull-apart basin was originally evolved from the deformation and sub-division of an E–W-trending paleotectonic structure (the Erzurum–Hasankale intermontane basin) during the Quaternary strike-slip neotectonic period (Fig. 13*c*).

3. Most of thrust to reverse faults in the Erzurum region is inherited from the pre-Quaternary paleotectonic period. Some of these thrust to reverse faults reactivated and emplaced older paleotectonic rock units onto the Quaternary neotectonic basin fill (Fig.7).

4. The seismicity of the Erzurum region is quite high as indicated by both the historical and recent destructive earthquakes (Tables 1 and 2). The most of settlements with a total population of over 766,000 are located on both the active fault segments and an unconsolidated basin fill. Finer-grained Quaternary alluvial sediments can be readily liquefied while the all-sized loose basin fill amplifies the intensity of earthquake. Therefore the active faults and the water-saturated basin fill have to be taken into account in both the earthquake hazard to earthquake risk analyses and the redesign of city planning of Erzurum and other settlements in the Erzurum region.

5. Return periods of peak earthquakes to be sourced from the active fault segments have to be determined in terms of detailed paleoseismological studies to be carried out in the Erzurum pull-apart basin and along its margin boundary faults.

6. A large-scale earthquake hazard map for the city of Erzurum and other settlements has to be prepared based on the active fault parameters and water-saturated basin fill.

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